THE GEOLOGY OF VANCOUVER AND VICINITY

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THE GEOLOGY *of* VANCOUVER *and* VICINITY

By

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PART I

INTRODUCTION AND PHYSIOGRAPHIC DESCRIPTION

CHAPTER I

GEOGRAPHIC INTRODUCTION

The Pacific Coast of the United States and Canada is bordered, throughout, by two parallel mountain chains, or successions of ranges, which are separated through most of their length by structural valleys of great magnitude, but are connected here and there by transverse ranges, or coalesce into mountain knots. The western chain rises in general somewhat steeply from the sea, with but little development of coastal plains at its foot. Its principal members are the mountains of Lower California, the group of seven islands off the coast of Southern California, the coast ranges of California and Oregon, the Olympics of Washington, and the Vancouver Range of British Columbia, which reappears to the northward in the Queen Charlotte Islands, and is continued in the Alaskan Islands and the St. Elias Range, where it reaches its maximum development at its junction with the east and west range of the southern part of the Alaskan Peninsula. Several portions of the western chain are traversed by submerged valleys and by the valleys of the Klamath and Columbia rivers. These interruptions, which occur at comparatively long intervals in the southern part, increasing in number and magnitude toward the north, include the entrances to the Gulf of Catalina, the Santa Barbara and San Pedro channels, the Golden Gate, the river valleys already mentioned, and the Strait of Juan de Fuca, followed to the north by the wide interval between the Vancouver and Queen Charlotte Islands, by the Dixon entrance to the north of the Queen Charlotte Islands, and by several smaller channels, which separate the Prince of Wales, Baranof, and Chicagof islands from one another and from the peninsula to the west of Lynn Canal.

The eastern mountain chain consists of the Sierra Madre, the Sierra Nevada, the Cascades, and the Coast Range of British Columbia and southeastern Alaska.

The transverse divides reach a maximum elevation in the Klamath Mountains, and from this point the trough as a whole may be said to pitch to the north and south, rising again toward Alaska.

The most southern extension of the geosyncline contains the waters of the Gulf of California, and the next, the Santa Barbara and San Pedro channels and the Gulf of Catalina, with the coastal plains adjacent to

them. The Coast Range is here represented by a fringe of islands which do not form a continuous barrier against the ocean, and the coast line behind them is not well provided with well-sheltered natural harbors. The cities of Los Angeles, San Diego, and Santa Barbara are situated on this coastal plain.

Still farther to the north the drainage of the great interior valley of California obtains access to the sea through the Golden Gate, a drowned river valley, whose inland extension furnishes a fine natural harbor, around which, at the entrance to the great valley of California, cluster the cities of San Francisco, Oakland, Berkeley, Alameda, San Rafael, and San Mateo.

The next harborage of importance occurs where the mouth of the Columbia River affords ingress to the Willamette Valley, and here the cities of Astoria, Portland, and Vancouver (Oregon) are situated.

Following the Willamette Valley are the Valley of Puget Sound and the Strait of Georgia, with their adjacent lowlands, to which access is obtained by the Strait of Juan de Fuca. In this case the submergence has extended well into the structural valley, whose northern part is largely submerged, while about its southern part there is sufficient lowland for the sites of the cities of Puget Sound, southeastern Vancouver Island, and the Fraser Valley. In this region and farther north the configuration of the coast has been profoundly modified by glaciation. The Cordilleran ice sheet or ice tongues from it which crossed the Coast Range formed large piedmont glaciers and filled the Gulf of Georgia with an ice stream which found its outlets through the Queen Charlotte Sound, the Strait of Juan de Fuca, and the Puget Sound valley.[1] The action of the ice resulted in deepening both the mountain valleys normal to the coast and those parallel to it near the edge of the range. By the agency either of ice erosion below sea-level or of a subsequent submergence, or both, a great number of inlets were produced which are connected by channels near their mouths in such a way as to form long inside waterways, which lie parallel to the coast behind a fringe of islands. The result is that, while the coast south of Cape Flattery has only an occasional harbor, the coasts north of it, whether of mainland or islands, are indented by many fiords and passages whose waters are completely sheltered, although in many cases, owing to their great depth, they do not furnish convenient anchorages. From the heads of many of the fiords valleys extend up to passes which cross the summit of the Coast Range, and from the passes corresponding valleys descend on the eastern side.

[1] G. M. Dawson, "Glaciation of the Cordillera," *American Geologist*, I (1890), 153.

Indeed, it seems probable that, previous to the Sierran uplift, the heads of many of the streams which now have their sources near the axis of the range and flow westward to the fiords were much farther east and carried part of the drainage of the interior, which has since been diverted to the Fraser[1] and other streams which maintained their courses across the axis of the uplift. The streams which thus held their courses across the uplift are the Fraser, Skeena, Nasse, Stikine, and the less important Taku. Their valleys provide the easier railway grades across the range, and good harborage is to be had at or near their mouths.

The Gulf of Georgia is divided from Puget Sound by a spur of the Cascade Range which extends northwestward from the mainland of Washington to the southeast end of Vancouver Island and is divided by a number of channels into the San Juan Islands. On the west side of the gulf the shores of Vancouver Island present a strip of lowland underlaid by coal-bearing Cretaceous rocks, which extends northwest to the end of the gulf. On the northeast side the Coast Range rises somewhat abruptly from the sea from the northwestern end of the gulf southeastward to Burrard Inlet, where the foot of the mountains turns almost directly east and leaves a lowland area to the south of the range on which the Fraser River debouches after emerging from its canyon between the Coast and the Skagit mountain ranges. The lowland is widest toward the west, where it extends into the state of Washington, and narrows eastwardly to an apex at about one hundred miles from the gulf. It is of a general triangular form, and is bounded on the north by the Coast Range, on the southeast by spurs from the Skagit Range of the Cascades, and on the west by the Gulf of Georgia. The part of it which lies north of the international boundary comprises the lower Fraser Valley, while the part which lies in the state of Washington is mainly comprised in the valley of the Nooksack River.

From the vicinity of Vancouver on the lowland two important passes lead across the Coast Range. The most important is that of the Fraser Canyon, which affords access by a "water grade" to the interior plateau region of British Columbia, especially the Thompson Valley and its tributary valleys, and has subordinate passes by way of the Coquhalla and Nicola valleys to the southern Okanagan and Kootenay regions. The second leads directly north from the head of Howe Sound by way of the Cheakamous Valley to the Upper Fraser Valley. A third route

[1] In the case of the Fraser Valley it is probable that a structural depression between the Coast and Cascade ranges has given the notable predominance enjoyed by that stream over others in the interior.

leaves the Fraser Valley at Agassiz and joins the second near Pemberton, by way of Harrison Lake, the Lillooet River, and Lillooet Lake.

At the northern end of the Gulf of Georgia the Coast Range and the Vancouver Island Range approach each other, a transverse axis of elevation connecting them. This has been so dissected, however, first by rivers and later by ice, that only the interstream uplands remain above sea-level, and the navigable channel of Johnstone Strait connects the Gulf of Georgia valley with that occupied by Queen Charlotte Sound and Hecate Strait. This section of the geosyncline is much more widely open to the sea on the west than the sections to the north or south. The distance from Cape Scott at the northern extremity of Vancouver Island to Cape St. James, the southernmost point of the Queen Charlotte Islands, is about 135 miles, and Dixon Entrance, to the north of the Queen Charlotte group, has a width of about 35 miles. Besides the mouths of the Skeena and the Nasse rivers, a number of important fiords indent the land along this part of the coast. Among them are the Portland Canal, Observatory Inlet, and Douglas, Gardner, Dean, and Burke channels, several of which have feasible railway routes leading from their heads across the Coast Range. The most important, from an economic point of view, probably is the Dean Channel.

The exceptionally deep submergence of this division of the coast trough has the following important results:

1. As already noted, the passages from it to the open ocean are very wide.

2. The advance of the sea against the Coast Range has left no lowlands favorable for cities along the coast except on islands, such as Banks Island, which are separated from the mainland by deep channels with mountainous sides. An exception to this occurs near the northern end of the strait in the Tsimpsian Peninsula, which has also the advantage of being adjacent to the mouth of the Skeena River. It affords sites for the city of Prince Rupert and the villages of Metlakatla and Port Simpson, the first and last of which have excellent harbors.

3. The extension of the tidewater far into the mountain valleys gives the fiords a much greater length than elsewhere on the coast. The available town sites are mainly on deltas formed in postglacial times at the heads of the fiords. They have the disadvantage of being surrounded by mountains, with possible outlets only in two directions—inland by the mountain passes and seaward by the fiords. The discovery of minerals near by has already determined the occupation of one such location at the head of the Portland Canal, and, while the life of

mining communities is in general short, it is probable that cities will eventually establish themselves in these positions. The limiting conditions on the commercial side are the amount of area available for the town, the small number of directions in which transportation routes diverge, the unproductive and sparsely settled nature of the surrounding highlands, and the greater facilities enjoyed by competing ports. Much will depend on how much of the interior is naturally tributary to each port and on the nature of the passes across the mountains. From the industrial side these limitations may be partly counterbalanced by the use of local resources, such as timber, mines, fisheries, and water-power. Where the valleys above tidewater contain a sufficient area of tillable land, small distributing centers will exist. These statements in general may also be applied to similar conditions existing on the mainland coast of the Gulf of Georgia to the northwest of Vancouver, where Howe Sound and Jervis, Toba, and Bute inlets are subject to the same conditions.

The most northerly section of the coast structural trough lies within the territory of Alaska and extends from the southern end of Prince of Wales Island to the head of the Lynn Canal. Here the submergence is much less marked, and the waters, instead of spreading broadly across the floor of the valley, as in the region last described, occupy channels cut into the valley floor in Pleistocene times. The northern region is in this respect the counterpart of the Puget Sound basin and of the divides intervening between Puget Sound and the Gulf of Georgia (San Juan Islands) and between the Gulf of Georgia and Queen Charlotte Sound. The lowlands are much more common along the mainland coast than in the British Columbia tract, and form many of the islands intervening between the Coast Range and the outer mountainous barrier on the Chicagof and Baranof islands. The waters of the fiords penetrate the mountains to comparatively short distances. Fort Wrangell, situated at the mouth of the Stikine on a low-lying island, and Skagway, at the head of the Lynn Canal, occupy what are probably the most important sites in the region. The former owed its rise to the development of the Cassiar mines in the early seventies, and the latter to the Klondike mines in the late nineties of the last century. Both have declined with the mining industry, and owing to their northerly position and the international boundary lying between them and their natural hinterland, whose ability to support a large population is as yet unproved, their probable importance is relatively small.

A feature of the coast region from Puget Sound northward which has noteworthy economic bearing is the presence of strong tidal currents,

which, at certain stages of the tide, affect navigation through the narrower waterways. Of these the most impotant for the purposes of this article are Seymour Narrows in Johnstone Strait, the narrows of Burrard Inlet between Stanley Park and the Capilano Delta, and Plumper's Pass, which lies to the south of Galiano Island on the route from Vancouver to the Pacific via the Strait of Juan de Fuca. Of these, the only one that causes serious delay is that at the Seymour Narrows, which affects only the northern coastwise traffic of Vancouver and the Puget Sound ports.

CHAPTER II

DESCRIPTION OF MAPPED AREA

The area covered in detail by this report is divided into two distinct portions, each of a definite physiographic type. The southern portion, which extends from the neighborhood of Burrard Inlet to the international boundary and beyond, is part of the floor of the great structural valley in which lie Puget Sound and the Gulf of Georgia. It is underlaid by the Eocene sediments of the Puget formation, upon which Pleistocene glacial and Recent alluvial deposits lie unconformably. Its surface is sculptured in comparatively low relief.

The area which lies north of Burrard Inlet presents a mountainous aspect and is a part of the southern margin of the Coast Range of British Columbia. It is underlaid largely by granitoid rocks, but there are some overlying areas of meta-igneous, meta-sedimentary, and later effusive rocks which locally affect the topography. The extreme relief in the region mapped is about 6,000 feet, and farther north, at Mount Garibaldi, this increases to 8,700 feet. Owing to this high relief, the topographic features are very striking and yield a definite record of a succession of physiographic cycles.

While the lowland has undergone a history which had much in common with the highland, it does not, owing to its low altitude, retain as distinct a set of erosional records, especially of the elder and some later stages, which were being sculptured in the mountain area while the lowland lay below sea-level. On the other hand, the depositional history is as well or better seen there, and the succession of interglacial and postglacial uplifts is in some cases better recorded. There seems little doubt that both areas formed part of a Pliocene or early Pleistocene peneplain, whose upwarp along the axis of the Coast Range Batholith has produced the present differentiation.

In general, the lowland presents the physiographic features of an area underlaid by truncated sedimentary strata of low dip, covered with glacial deposits, and further modified by the presence of a river of large dimensions. The mountain area has the features due to stream erosion of an upland largely of massive igneous rocks, affected by successive periods of uplift and modified by later glaciation.

A. THE LOWLAND SECTION

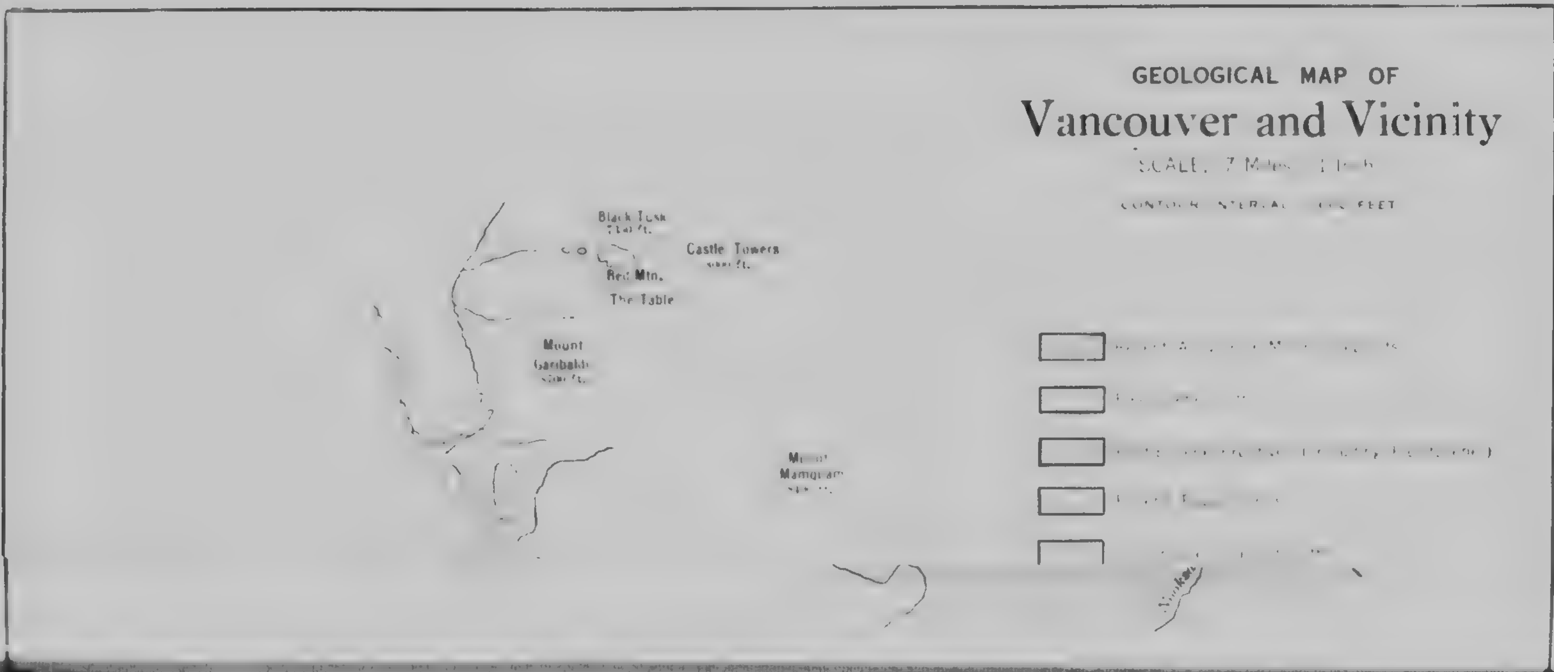
The lowland to the south of Burrard Inlet may for convenience of description be divided into four parts, which are in order from north to south: (1) the Burrard Peninsula; (2) the Fraser Delta; (3) the Surrey terrace; (4) a morainic area extending to the international boundary.

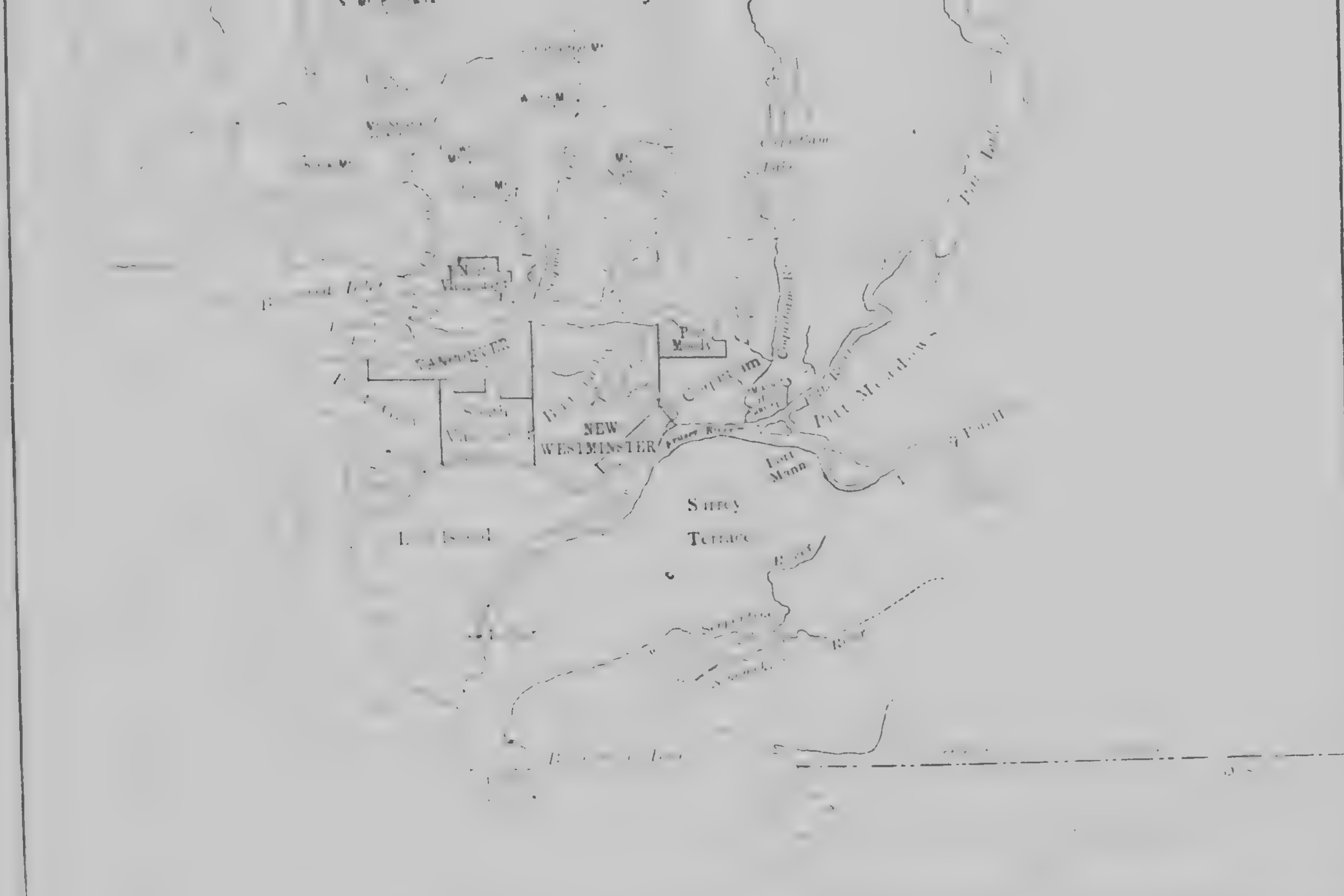
1. *The Burrard Peninsula.*—The Burrard Peninsula is bounded by the Fraser River on the south and Burrard Inlet on the north, and may be considered as extending from Point Grey at its western extremity to the Pitt River on the east. Its maximum width from north to south is about $8\frac{1}{2}$ miles, and its length from east to west about $22\frac{1}{2}$ miles. Its surface in most parts is not more than 400 feet above sea-level, except along its northern edge between the second narrows of Burrard Inlet and Port Moody, where a ridge from 900 to 1,300 feet high borders the south side of the inlet. The Coquitlam River traverses the eastern end of the peninsula and enters the Fraser a short distance west of the Pitt.

The Burrard Peninsula consists of two ridges, both of which have an east-west trend, with a valley between. It is covered with drift, the character of which will be described later. The underlying rocks belong to the Puget formation. The southern ridge extends from Point Grey on the west to the junction of the Brunette Creek and the Fraser River at Sapperton, a distance of $17\frac{1}{2}$ miles. It extends 5 miles farther west than the northern ridge, from which it is separated by a marked depression which forms the valley of Brunette Creek, Burnaby and Deer lakes, and Still Creek, and beyond a divide to the west contains the waters of the shallow inlet known as False Creek. The general direction of the valley from the Fraser to False Creek is west by north.

The southern ridge is occupied by the city of New Westminster at its southeastern end, by the southern part of the municipality of Burnaby, by the entire municipalities of South Vancouver and Point Grey, and by the southern part of the city of Vancouver.

The northern ridge of the Burrard Peninsula extends in an east-by-south direction from Stanley Park to the junction of the Pitt and Fraser rivers, a distance of about 18 miles, and is somewhat less in area, though considerably greater in altitude, than the southern ridge. Its eastern end is occupied by the municipalities of Coquitlam and Burnaby, while on its low western end is situated the principal part of the city of Vancouver. Its northern edge lies along the south side of Burrard Inlet to its head at Port Moody, and from there along the depression which runs from the head of the inlet westward to Westminster Junction on the


GEOLOGICAL MAP OF
Vancouver and Vicinity
Black Tusk
Castle Towers
Red Mtn.
The Table
Mount
Garibaldi



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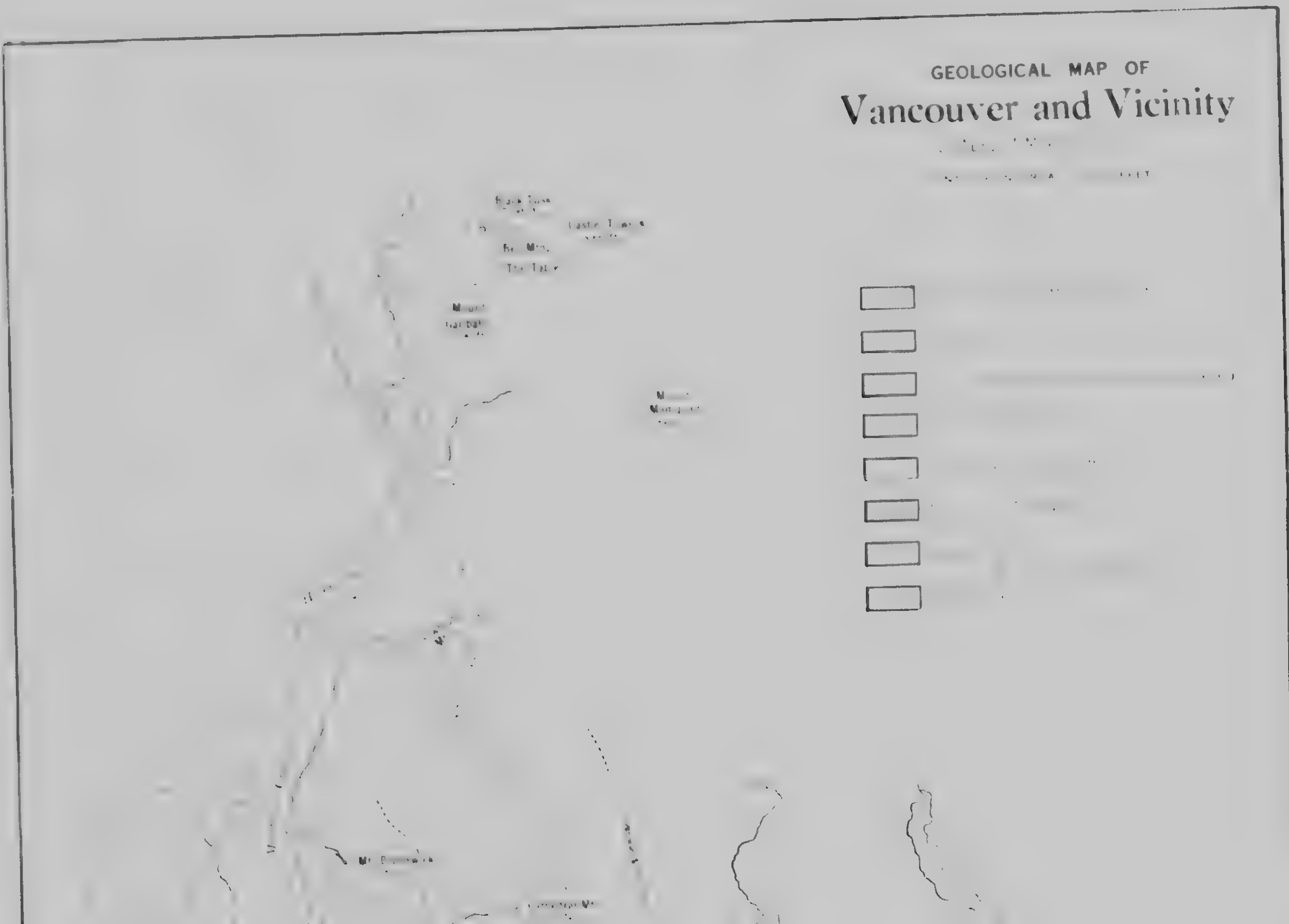
GEOLOGICAL MAP OF
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Coquitlam River, where it debouches on the alluvial plain known as Pitt Meadows, which extends for some distance up the Pitt River and southward to the Fraser. Between the Coquitlam and Pitt rivers at the east end of the area is an elevation known as Mary's Hill, which is a detached outlier of the northern Burrard Peninsula ridge. The Burrard Inlet trough, with its eastward extension to the Pitt Meadows, and the Burnaby Lake False Creek trough seem undoubtedly to be old channels of the Fraser River which have been abandoned in favor of the more southerly channel owing to the elevation of the land to the north toward the mountain axis. Both of these depressions appear to be incised in the underlying Eocene rocks. Burrard Inlet is undoubtedly of erosional, not structural, origin, and such evidence as is available points to the same conclusion for the valley of Burnaby Lake and False Creek. The present channel of the Fraser seems to lie over a depression in the surface of the Puget formation, which is probably in part at least structural, as no outcrops of rock are known along the shores to the south as far as the international boundary. The excavations for the Fraser River bridge at New Westminster show that the rock surface is there about 150 feet below high tide. Two and one-third miles farther north it is exposed in the bed of the Brunette Creek, at an elevation nearly 200 feet higher. There is a rock outcrop at Fairview Heights, also, about 300 feet above sea-level. The mantle of till in this part of the peninsula is, however, so continuous and thick that in the absence of numerous borings an accurate description of the underlying rock surface must be deferred.

Along the margins of the Burrard Peninsula are a number of low areas, either tide-flats, as on the north side, or flood-plains bordering the Fraser, Coquitlam, Pitt, and Brunette rivers. These, while part of the peninsula, can with more propriety be described in connection with the delta and flood-plain areas of the next division, with which, also, a brief description of the Fraser Valley may be included.

The western part of Point Grey is of origin similar to the Surrey terrace, and may properly be referred to in that connection.

2. *The Fraser Delta.*—The Fraser River, after debouching from the canyon through which it passes between the Skagit and Coast ranges, becomes at once a depositing stream at a point nearly 100 miles from its mouth. Numerous bars of gravel and sand, which have formerly, and even recently, afforded alluvial gold, are to be seen, especially above Agassiz. Below this, many islands of silt occur in the channel of the river, while on both sides flood-plains are deployed. These are especially

noteworthy on the south side of the river, where the Chilliwack, Matsqui, and Langley prairies furnish extensive areas of land, which, protected from floods by a system of dikes, have proved of high fertility. Lower down, on the north side, the Pitt Meadows, already mentioned, have been formed by the silting up of the shallow southern end of Pitt Lake, a fiord-like loch which, when the sea stood at a somewhat higher level than at present, was in reality a fiord extending northward from the Fraser estuary as the North Arm does from Burrard Inlet. On the south side of the river a narrower flood-plain extends still farther downstream and is occupied by the town sites of Port Mann and South Westminster. It is terminated by a spur of glacial drift and stratified deposits which projects northwestward to the main channel at Annieville, just below New Westminster, and divides the flood-plain from the head of the modern delta.

On the north side of the river, after passing the cut-bank of Mary's Hill, another flood-plain about half a mile in maximum width extends from the Coquitlam River to the mouth of Brunette Creek. It is partly occupied by a number of sawmills and other industries, while certain parts of its surface on which a deposit of peat has developed are now being reclaimed by trenching for agricultural purposes.

At various points the flood-plains are interrupted by elevations. Some of them are projections of the underlying rocks, either the granitic rocks of the Coast Batholith or the sedimentary strata of the Puget formation, as at Matsqui; and some of them are flat-topped accumulations of alluvial material, as at Langley, deposited when the land was relatively lower than at present, and the deposited sands and gravels attained a level about coincident with the mean height of the water surface. In other places there are drift-hills which were truncated or terraced by wave-action. The northern shore line of the former estuary just north of the Fraser is marked by numerous well-defined terraces, with their accompanying beach deposits, as at Mission Junction (42 miles east of Vancouver). (See table, page 94.)

The tides still affect the flow of the river as far upstream as Langley, a distance of over 30 miles from the mouth, and also the waters of Pitt River and Lake. The arresting of the current in this part of the river twice daily has no doubt operated effectively to increase the deposition of silts in such areas as Pitt Meadows, while the heavy scour due to its rapid ebb has doubtless contributed to the deepening of the channels. That of the Fraser at New Westminster bridge has more than 70 feet of water.

The apex of the delta is opposite the city of New Westminster, while its front lies 15 miles westward and extends from the headland of Point

Grey in a sinuous line S. 20° E. to Point Roberts, a distance of about 17 miles. The Fraser traverses it by two principal distributaries, of which the southern is the larger. The northern arm flows close to the southern side of the Burrard Peninsula ridge, at the foot of which are a few flat areas which properly belong to the delta. In and between the distributaries are some forty-five islands, of which the largest is Lulu Island. Sea, Westham, and Annacis islands are also of considerable size.

A large part of the delta lies to the south of the main channel and extends seaward from the western face of the Surrey terrace. Its southwestern margin projects southward as far as the former island of Point Roberts, which it has thus connected with the mainland by a wide spit, forming at the same time a shallow bay to the east of the point, known as Boundary Bay.

The delta is one of the richest agricultural areas in the province. A considerable part of the upper end of Lulu Island is covered with peat. The depth of the delta deposit at its seaward edge is unknown to the writer.

The level of the delta lands is little, if at all, above mean high tide, and they have been diked against the higher spring tides.

In front of the unsubmerged portion of the delta a submarine delta terrace, known locally as the "sand-heads," extends some 5 miles seaward, and its front describes roughly an arc of some 120° extending from Point Grey to Point Roberts.[1] The navigable channel which extends across them has shown some tendency to shift its position, and it is proposed to fix it permanently by the construction of jetties across the banks, between which the scour of the current would be sufficient to maintain a channel for ships. The sand-heads are largely bare at low tide.

Besides the sand-heads, which are divided by the main channel into the Roberts and Sturgeon banks, a submerged terrace known as the Spanish Bank lies on the north side of Point Grey. Probably it is to be considered as largely formed by the wave-cutting of the deposits which form the end of the Burrard Peninsula. It is probable also that a considerable part of the Sturgeon Bank, which lies below the cliffs on the south side of Point Grey, is of similar origin. On each side a bowlder pavement in front of the cliffs is succeeded farther out by deposits composed of finer materials carried out by the undertow.

Extending from the northeast corner of Boundary Bay to the Fraser River near Barnston Island is a trough floored by alluvial deposit, which is drained by the Serpentine and Nikomeki rivers. These are small tidal

[1] See O. E. LeRoy, *Geol. Surv. Canada, Publication 996*.

treams which flow into Boundary Bay. There is no doubt that this alley, at a comparatively late period, was occupied by a distributary of the Fraser. It is of economic importance at present as furnishing an excellent railroad route between the Fraser Valley and the Fraser Delta, and for agricultural purposes.

3. *The Surrey terrace.*—To the south of the Fraser, opposite the eastern end of the Burrard Peninsula, lies a flat-topped area which rises some 230 or more feet above the surrounding delta lands and flood-plains. Its dimensions are roughly 7 miles by 8, and its longer axis lies in an east-northeast direction from its southwestern extremity. It is bounded on all sides by steep slopes which exhibit in many places river- or wave-cut terraces, and consists of delta-like deposits overlaid by a thin sheet of till. The most noticeable feature of this area is the extreme levelness of its upper surface, varied here and there by a few channel-like depressions of shallow depth, except where dissected by recent ravines. The till sheet, which is usually from 3 to 5 feet in thickness, has produced little variation in the flatness of the topography. The surface is still largely forested, but where cleared the weathered till has been found to afford excellent soil for fruit culture.

According to LeRoy,[1] Point Roberts, at the southwest extremity of the Fraser Delta, belongs genetically to the same type as the Surrey terrace and the western end of Point Grey. The Surrey terrace and Point Roberts are now connected by the deposits of the recent delta.

4. *The boundary morainic area.*—To the south of the Serpentine-Nikomeki valley the land rises again to a height of 400 or 500 feet, the upper surface being somewhat irregular. The northern part of this area is possibly underlaid by deposits similar to those of the Surrey terrace, but these are immediately succeeded to the south by a heavy morainic deposit, which probably marks the southern boundary of the interglacial Fraser estuary. Wave-action on the eastern side of Boundary Bay, along which this area lies, has cut a sea cliff some 200 feet in height in which a section of the Vashon and Admiralty tills (pp. 82 ff.) and intermediate stratified deposits is well exposed.

B. THE HIGHLAND SECTION

As already stated, the region north of Burrard Inlet and the Fraser Valley is part of the southern portion of the Coast Range of British Columbia. The margin of the range which faces the Pacific has throughout most of its length a northwest trend, but at the southern end of the

[1] O. E. LeRoy, [illegible]

range it alters to an east-and-west direction, and follows that bearing along the north side of Burrard Inlet and the Fraser Valley. Its margin here, as elsewhere, is divided into numerous spurs by glaciated valleys of varying depth, some of them considerably below sea-level, others above it. The direction of these valleys is north and south, or roughly perpendicular to Burrard Inlet. Between the valleys the crest lines of most of the spurs rise from the lowlands in gentle resupinate curves whose steepest slopes are seldom more than 18° from the horizontal, while the average is not above 12°, and in some cases as low as 7° or 8°. At elevations varying from 3,000 to 3,800 feet the rising profiles are interrupted by a set of rock-cut terraces with horizontal or very gently sloping tops, many of them a mile or more in width, beyond which the most southerly peaks of the range rise somewhat abruptly to an altitude which places them near the continuation of the general curve of the profile. Northward, toward the heart of the range, the summits show a continued general accordance. The surface in which, speaking in general terms, they may be said to lie flattens as an elevation of about 8,000 feet is approached, and continues nearly horizontal for some distance across the center of the range. This surface is interpreted as an upwarped peneplain. (See chapter xi, page 96.) A few peaks rise above the general level. Among them in this region is the volcanic cone of Mount Garibaldi, 8,700 feet in altitude.

Many of the summits themselves are very sharp "horns," shaped by cirque cutting, while others are flat-topped. Below them are even-topped connecting ridges and spurs, which also are accordant, and long concave slopes, some of them terraced, descending at low angles through vertical distances as great as 3,000 feet in some cases. Below these ridges and slopes are profound steep-sided valleys of the canyon type, in some cases more than 4,000 feet deep, whose bottoms have, as a rule, been well rounded by valley glaciers. Many of their slopes near the upper limit of the ice reach an angle of 50°. In the bottoms of the glaciated valleys postglacial erosion has produced young steep-sided canyons whose depth may reach 400 feet.

The even-topped ridges and gently concave slopes below the summits, when traced to the margin of the range, grade down to the rock cut terraces already mentioned as indenting the profile of the marginal spurs. The general elevation of the flat surfaces increases gradually from 3,800 feet at the southern margin of the range to 5,200 feet and over at the Black Tusk Mountain, some 40 miles to the north. These gentler upper slopes and flat-topped ridges have been interpreted as the remaining

surfaces of maturely developed valleys which were cut below the summit level, after a period of upwarp which followed an earlier planation. The stage of uplift and erosion which is represented by a similar set of topographic features in the Cascade Mountains of central Washington has been called the Entiat, from the basin of the Entiat River, where it is well recorded.[1] In the Coast Range region of British Columbia the Entiat (?) surfaces have been modified, first by a general movement of overriding ice, and secondly during later stages of glaciation by local glaciers, which remain on the upper slopes even down to the present time and have developed cirques to such an extent that many of the original ridges are represented only by knife-edge divides projecting between adjoining névés. Where abandoned by their glaciers many of these cirques are merely shallow saucer-like depressions with sloping bottoms. In other cases they have been excavated deeply enough to form rock basins which contain small lakes.

A period of canyon-cutting followed the elevation of the land subsequent to the development of the wide Entiat valley floors. To this stage the name Twisp has been applied by Smith and Willis,[2] and the later modification of the canyons by valley glaciers has been designated the Chelan stage. The Cordilleran ice sheet did not cover the ent Lake Chelan region, but in the Vancouver region the range seems have been covered by a nearly continuous ice sheet, above which only the higher peaks projected. The later valley glaciers were phases in the recession of the ice sheet, and their effect on the valleys has therefore been somewhat different from that in the region farther south. There are valleys whose upper slopes are parts of a V-shaped cross-section, while the bottoms are well rounded; there are others whose cross-sections appear to be made up of two U-shaped valleys, one within the other; and there are still others which are simply U-shaped. Lateral cirques which contained lobes of the valley glacier are common. Some of the valleys which were transverse to the ice movement show comparatively little rounding, and it is probable that they were occupied by stagnant or nearly stagnant ice during the maximum glaciation and escaped the effects of prolonged valley glaciation during the recessional stages.

Valleys of the Twisp and Chelan stages, many of which extend below tidewater, form the fiords which are so prominent a feature of the coast.

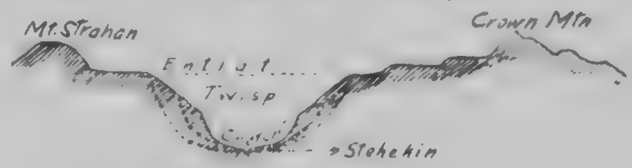
The period of the postglacial erosion, mainly removal of drift, has been designated by the name Stehekin in the Lake Chelan country, and

[1] G. O. Smith and Bailey Willis, *U.S. Geol. Surv., Professional Paper 19.*

[2] *Ibid.*

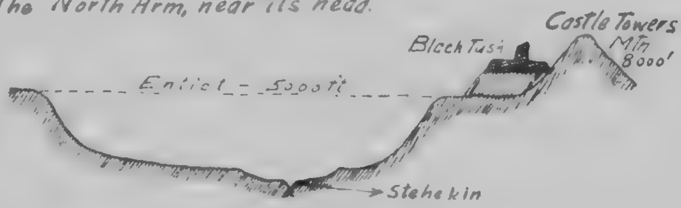
is represented in the Coast Range by similar features, and also by rock-cut canyons and the building of deltas at the mouths of streams. It has also been a period of considerable uplift. The evidence of this consists of raised deltas and wave-cut terraces in the drift along the margin of the highland and in the lowland areas. The five distinct

Diagrammatic Cross-Sections of Valleys.



1. Capilano Valley. The Chelan rounding seems less higher up the valley.

2. The North Arm, near its head.



3. The lower Cheakamous Valley.

Fig. 2

stages of physiographic development recognized in the Cascades of Washington may therefore be provisionally correlated with those of the Coast Range of British Columbia. They may be recapitulated as follows:

1. Methow peneplain: represented by accordant summits, or terraces below summits which stood above the peneplain as monadnocks.
2. Entiat stage: represented by the mature valleys developed in the upwarped Methow surface.

Twisp stage: the time of the cutting of deep V-shaped canyons below the broad Entiat valley floors, after the uplift of the latter.

4. Chelan stage: the time of glaciation, with its attendant modifications of previous topography. These modifications were greatest in the Twisp canyons.

5. Stehekin stage: represented by (*a*) the postglacial stream cutting in drift or bedrock, (*b*) by terraces, and (*c*) by delta deposits.

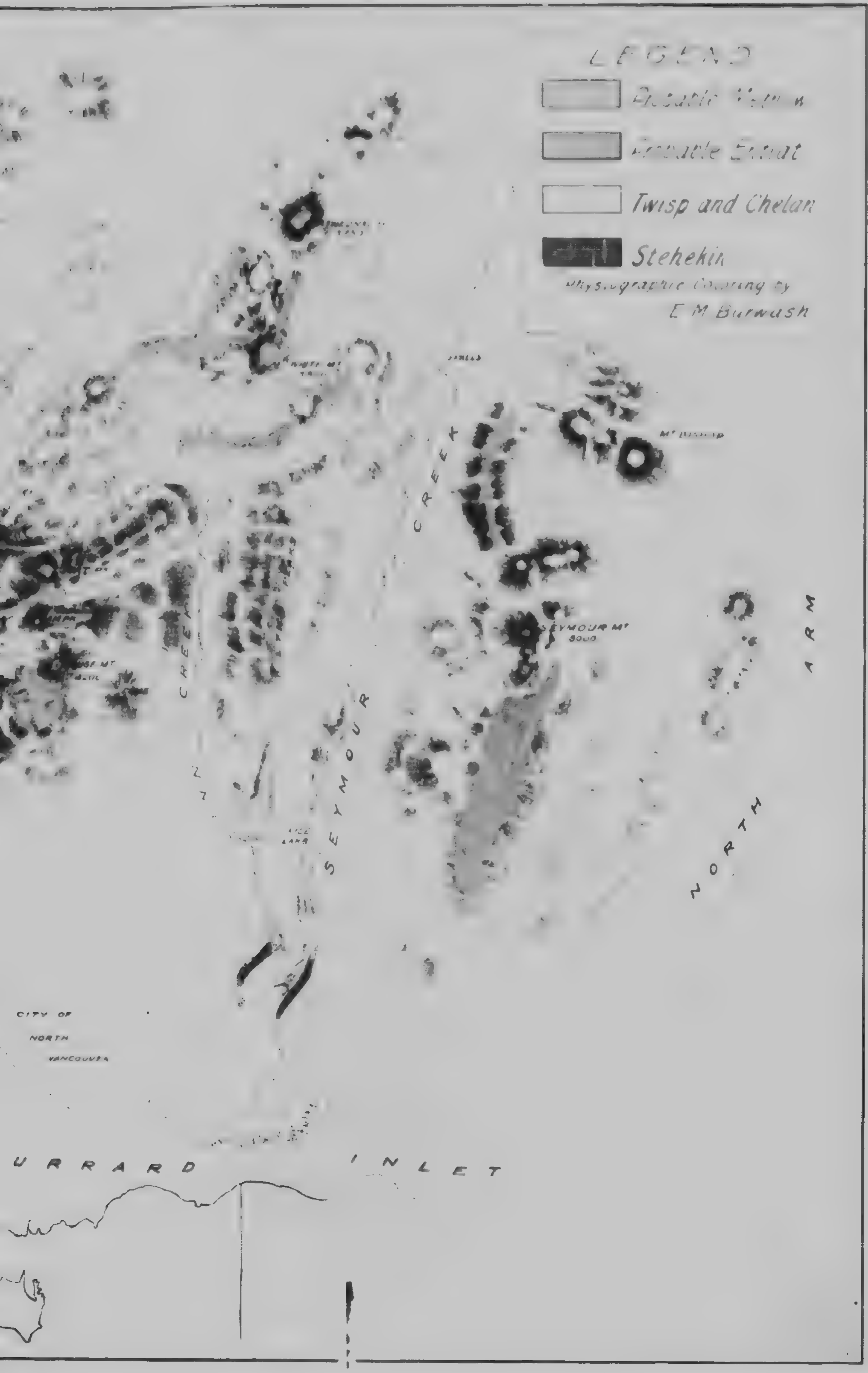
A further discussion of the origin and age of these topographic features and their correlation will be found in chapter xi on "Physiographic and Glacial History."

Within the area studied in detail there are three principal mountain spurs, one subordinate spur, and the valleys of the Capilano, Lynn, and Seymour creeks, which separate them. These valleys are essentially the same in type as those of the fiords of Howe Sound and the North Arm which flank the area on the west and east, or as the valleys of Coquitlam, Pitt, Stave, or Harrison lakes farther east along the southern margin of the range. All of these except that of Coquitlam Lake have a considerable depth below sea-level, and all are deeper in their middle or upper reaches than near their mouths. In the time immediately following the recession of the ice the same thing was true of the valleys of the Capilano, Lynn, and Seymour. They at first contained fiords, which gave place to lakes as uplift progressed, and these were later drained by the cutting of postglacial canyons through the rock and drift barriers which retained their waters. The existence of these barriers of rock near the mouths of the valleys seems to be connected with the shallowing and lateral spreading of the ice stream as it emerged from the confining valley walls near the margin of the range. The pressure of the glacier on its bed was in consequence less, and erosion was less powerful than in the narrower and higher-walled parts of the valley. As the glacier receded from the lowland into the mountain valley its front probably rested for some time against the rocky obstruction, with the result that an unusual amount of morainic deposit was left there.

The most westerly spur, that which stands between Howe Sound and the Capilano Valley, has a flat-topped southerly extension known as Hollyburn Ridge, while the "Methow" summits which succeed each other along its crest are, in order, from south to north, Black Mountain (4,200 feet), Mount Strahan (5,000 feet), The Lions (5,800 feet), and Mount Brunswick ([illegible] feet). Two of these summits are composed of [illegible], Mount Strahan of Texadan schist, and

HOWE


SOUND
MT STRAHAN
HOLLYBURN
PT ATKINSON
ENGLISH BAY
MAP SHEWING
TOPOGRAPHY
OF THE
VANCOUVER RANGE
B.C.
Scale of Miles
CITY OF VANCOUVER



Twisp and Chelan
Stehekin
E M Burwash
SEYMOUR MT
5000
CREEK
SEYMOUR
NORTH ARM
CITY OF
NORTH
VANCOUVER
INLET

Mount Brunswick of Britannia slates and quartzites, with interbedded porphyrites. The others are composed of the massive diorite of the Coast Batholith. The connecting ridges intervening between the higher summits from Mount Strahan to Mount Brunswick have generally very narrow crests, which drop abruptly into large cirques on either side. The cirques are separated at intervals by spurs whose crests are also narrow. The top of the ridge is divided into subordinate summits, separated by trough valleys, some of which have been rendered U-shaped by the ice which, at its maximum, crossed the spur diagonally.

The central spur lies between Capilano and Seymour creeks and is bifurcated by the valley of Lynn Creek, whose headwaters extend some 9 miles from tidewater. The western fork or subordinate spur has a plateau-like terrace at 3,800 feet, immediately north of which is the summit of Grouse Mountain (4,200 feet), followed at short intervals northward by Dam Mountain (4,500 feet) and Goat Mountain (4,700 feet). Extending east and west from Goat Mountain are typical flat topped Entiat (?) spurs at an elevation considerably below the summit. Crown Mountain, which lies immediately north of Goat Mountain, may rise above the peneplain. It is 5,500 feet high and is a sharp knife-edge of granitoid rock which is being rapidly eroded. Its western end descends by a number of terrace-like steps.

From Crown Mountain a fairly even-topped ridge, known as Palisade Ridge, extends in a northeasterly direction to White Mountain, whose flat-topped summit has an elevation of 5,200 feet. To the north of White Mountain is Cathedral Mountain (5,800 feet). Beyond Cathedral the spur sinks to a ridge of even crest line, known as Serpentine Ridge. This represents the Entiat stage. Its elevation opposite the headwaters of the east arm of the Capilano is 4,450 feet, and toward the headwaters of Seymour Creek, farther north, it rises to about 5,000 feet in the neighborhood of the Saw Tooth Mountain.

Extending southward from White Mountain between the Lynn and Seymour creeks is a small spur whose broken crest line represents the reduction due to the lateral erosion of the valleys on each side of it. It forms the eastern fork of the Capilano-Seymour spur and is known as Lynn Ridge. The northern part of Lynn Ridge is composed in its upper part of Texadan rocks, which extend from it northwestward across the Lynn Valley and the eastern spur of Goat Mountain to the top of Palisade Ridge. The underlying batholith is exposed on the west side of Lynn Ridge near its base as far north as the Swayne copper mines, which are situated at the contact. The upper surface of the batholith

gradually rises to the top of the ridge, the southern part of which is composed wholly of diorite.

Seymour Ridge, which occupies the area between Seymour Creek and the North Arm of Burrard Inlet, has at its southern end plateau-like terraces at 3,200, 3,850, and 4,050 feet respectively. Small lakes on their surfaces occupy the bottoms of cirques cut in the terrace fronts. To the north is Pump Peak (4,600 feet), followed by Mount Seymour (5,000 feet). Beyond this the ridge is lower as far as Mount Bishop, whose elevation is 4,800 feet, somewhat below Mount Seymour.

Beyond the mapped area a reconnaissance was carried over the divide at the headwaters of Seymour Creek, and thence down the valley of Stawmus Creek to the head of Howe Sound. The lake in which Seymour Creek originates has an elevation of 3,300 feet, and the Saw Tooth Range, at no great distance, is probably at least 6,000 feet in elevation. To the northeast of the head of Howe Sound the range reaches the height of 8,400 feet in Mount Mamquam, a granitic massif which is overtopped, within this region, only by Mount Garibaldi (8,700 feet), a volcanic cone of Pleistocene age.

Following up the streams of the mountain area above the canyons which they have cut through the rock and drift barriers near their mouths, their channels are in general shallow cuts in the drift of the U-shaped valley bottom, and thickly strewn with the bowlders derived from it. Near the heads of the valleys steeper gradients and deeper drift-cuts are met with. The gradient of the Capilano for the first seven miles from its mouth is about 70 feet per mile, that of the Seymour for the first twenty-one miles about 60 feet per mile. The gradient of the Seymour in the upper four miles of its course is about 500 feet per mile, and in the case of the lateral tributaries this gradient is much exceeded.[1]

The steeper section of the stream profiles toward their heads consists, in many cases, of a number of terrace-like steps, due perhaps to the cutting of successive cirques by the receding valley glaciers, to the confluence of tributary glaciers at the point where the deepening occurs, or to a narrowing of the valley. The edges of these steps have in many cases been notched by very steep-sided canyons; in others the streams cascade over them. At the summit of the pass or near it there is often a level meadow-like area, where the stream has its source in a small lake. The Seymour is a case of this kind, and there the pass lies between mountains which rise considerably above it. Others, like the Lynn, flow from

[1] Stream data obtained from *Report of Water Rights Branch, Department of Lands* (Victoria), 1913.

lakes which lie in steep-sided cirques, many hundred feet below the thin-edged divides, which are in general not much lower than the summits on either side.

The heavy precipitation on the mountain area nourishes a luxuriant growth of Douglas fir (*Pseudotsuga douglasii*) and giant cedar (*Thuja gigantea*) up to about 3,000 feet. Above this the character of the vegetation changes, and the forests become thinner, passing from the Transition zone successively through the Canadian and Hudsonian zones of vegetation until the snow line is reached. The Entiat slopes are in general thinly afforested or alpine meadows diversified by clumps of trees.

The Twisp and Chelan features of the topography may therefore be said to include the chief forest areas. The mountain region here described finds its chief economic importance as a source of water supply and electric power for the cities of the lowland. Many of the Entiat uplands furnish broad areas where, although thick forest cover is absent, extreme rapidity of run-off is somewhat hindered by mosses, heather, and similar vegetation, and where in many sheltered places slowly melting snows remain through a considerable part of the summer.

C. CLIMATE AND CLIMATIC DATA

The area discussed in this study furnishes one of the best possible examples of the effect on precipitation of a mountain range interposed in the path of moisture-laden winds from the ocean. The following table compiled for points ranging from the western part of the Fraser Delta to Coquitlam Lake, in the northeastern part of the region and well up in the mountain range, will serve to convey the facts with sufficient clearness:

Observing Station	Precipitation 1913–14
Ladner, near front of Fraser Delta	26.81
Vancouver (Burrard Peninsula ridge)	55.75
Coquitlam Lake	130.82
Ashcroft (east side of Coast Range)	5.00

More detailed information as to precipitation in the vicinity of Vancouver may be obtained from Table I, page 22, which indicates its distribution throughout the year.[1] The months which have the greatest precipitation are November and January; those which have the least, July and August.

[1] Compare also *Report of Water Rights Branch, Department of Lands* (Victoria), 1914, p. H 26 ff

TABLE I

A. VANCOUVER

TEMPERATURE

January	[illegible]	[illegible] 4	[illegible]	[illegible]
February	[illegible]	40 0	[illegible]	[illegible]
March	42 0	41 [illegible]	[illegible]	44 [illegible]
April	44 0	47 0	[illegible]	[illegible]
May	[illegible]	[illegible]	[illegible]	[illegible] 4
June	[illegible]	[illegible]	[illegible]	[illegible]
July	[illegible] 9	63 0	[illegible]	[illegible]
August	[illegible]	[illegible]	[illegible]	[illegible]
September	56 0	56 5	[illegible]	54 [illegible]
October	[illegible]	[illegible]	47 [illegible]	[illegible] 4
November	[illegible]	[illegible]	[illegible] 4	44 [illegible]
December	[illegible] 7	[illegible]	40 1	[illegible] 4
Average year	48 05	49 73	[illegible]	50 25
Highest temperature	[illegible] 2	85 1	82 0	81 6
Lowest temperature	[illegible] 4	15 8	12 0	15 5

ANNUAL PRECIPITATION

Rainfall	45 91	50 12	50 34	52 04
Snowfall	[illegible] 55	0 25	[illegible] 70	17 45
Total precipitation	[illegible] 27	57 05	[illegible]	[illegible]
Bright sunshine (hours and minutes)	1,793 54	1,044 18	1,652 00	1,747 00
Days with 0".01 or more of precipitation	168	175	[illegible]	

B. TEN YEAR MEANS, VANCOUVER

TEMPERATURE AND PRECIPITATION

Month	Mean (of years)	Mean Max	Mean Min	Monthly Range	Absolute Max	Absolute Min	Precip.	Av. No. of Rain Days
January	36 3	40 1	32 5	7 6	55	2	8 83	10
February	[illegible]	44 7	[illegible]	[illegible]	58	11	[illegible] 70	10
March	42 6	49 [illegible]	35 [illegible]	14 6	61	15	4 60	14
April	47 1	56 1	38 1	18 0	79	28	3 42	16
May	53 5	[illegible] 5	44 4	18 1	80	33	[illegible] 60	16
June	58 2	67 7	48 7	19 0	88	36	3 28	16
July	62 8	[illegible] 8	52 7	20 1	90	43	1 23	19
August	60 0	72 1	51 9	20 2	92	41	1 47	[illegible]
September	55 0	63 9	46 9	17 0	82	36	5 40	15
October	50 0	57 6	42 3	15 3	69	23	5 48	12
November	41 4	46 7	36 0	10 7	74	15	10 00	9
December	36 6	44 1	[illegible] 1	[illegible]	58	22	7 84	8
Year	48 9	72 8	[illegible]	15 2	92	2	62 42	[illegible]

* The climatic data [illegible], have been supplied by Mr. [illegible], Dominion meteorologist at Vancouver [illegible] the Dominion Meteorological Office at Toronto

TABLE I—*Continued*

C. Winds, Vancouver

SUMMARY OF WIND FOR YEAR 1914

	Prevailing Direction	Miles	Greatest Velocity	Ten-Year Mean	1914
January	East	3,200	25	8.83	10.56*
February	East	3,012	24	0.79	4.8[illegible]
March	East	2,900	16	4.90	3.33
April	East	3,100	15	3.42	3.[illegible]
May	West	2,037	18	3.60	0.74
June	West	2,050	16	3.28	3.58
July	West	3,008	16	1.23	0.4
August	Northwest	2,900	18	1.47	0.7[illegible]
September	East	3,400	20	5.49	6.8[illegible]
October	East	2,588	17	5.48	
November	East	2,794	20	10.49	
December	East	2,021	12	7.84	

* *Report of Water Rights Branch* (Victoria), 1914

SUMMARY OF WIND FOR YEAR 1911

Number of winds from—

N.	N.E.	E.	S.E.	S.	W.	N.W.	Calm	S.W.
19	25	184	106	20	73	67	197	39

Average hourly velocity, 3.4

Maximum velocity, 18.0 W.

D. New Westminster

	1911	1912	
Average temperature—			
January	30.8	35.5	30.5
July	64.0	64.1	6[illegible]
Year	47.67	49.48	48.43
Highest temperature	90.4	90.4	89.5
Lowest temperature		13.6	8.[illegible]
Rainfall	45.22	55.54	52.04
Snowfall	54.50	19.90	70.00
Total precipitation	50.67	57.53	59.10

TABLE II

A. Victoria

	1911	1912	1913
Average temperature	48.76	50.33	49.48
Highest temperature	89.5	89.8	85.8
Lowest temperature	14.2	23.5	21.0
Rainfall	22.55	20.53	23.00
Snowfall	10.35	3.20	8.40
Total precipitation	24.19	29.85	23.84
Bright sunshine (hours)	1,932.30	1,661.12	1,606.30

TABLE II—*Continued*

B. PRINCE RUPERT

	1911	[illegible]	1913
Average temperature	43 54	46 70	45 67
Highest temperature	83 0	85 0	78 0
Lowest temperature	3.0	8 0	4 0
Rainfall	92 72	87 95	123.78
Snowfall	108 73	20 60	27 0
Total precipitation	103 59	90 02	126 48

C. KAMLOOPS

	1911	1912	1913
Average temperature	44 31	46.52	45 16
Highest temperature	99 5	101 0	98 8
Lowest temperature	30 5	−18 0	−18 8
Rainfall	4 87	11 59	7 27
Snowfall	34 90	18 75	26 85
Total precipitation	8.36	13.47	9 95
Bright sunshine (hours)	2,204 48	1,866 48	1,911 54

A peculiarity of the lowland area which applies also to Burrard Inlet, and appears to be connected with the proximity of the mountains, is the notable absence of high winds. Storms of considerable violence occur on the Gulf of Georgia, while only moderate or gentle winds are experienced at Vancouver and New Westminster. Though Vancouver is in the latitude of prevailing westerly winds, it will be noted that during the colder months Vancouver records show prevailing easterly winds. This is no doubt a local effect, due to the low temperatures on the mountains, which is of the nature of an eddy, caused by the snow-chilled air of the mountains replacing the warmer air of the lowlands.[1] The change from westerly to easterly is accompanied by a sharp increase in precipitation and fog (Table I, C, p. 23).

Vancouver, as records of ten years' observations show, has an absolute temperature range of about 90°[2] (2° to 92°), and an annual mean temperature of 48° (Table I, B, p. 22).

The range of temperature and variation in ratio of snowfall to rainfall within the mapped area is of course large, since the climate as a whole varies from the mild, temperate oceanic climate at sea-level to a subarctic climate on the higher mountains.

[1] Local monsoon. [2] Fahrenheit.

The high precipitation on the mountain section has the local advantage of providing an abundant and pure water supply and water-power which, though still largely undeveloped, furnishes the cities of the lowlands with cheap electricity. The luxuriant forest growth of the lower mountain slopes is also referable to the same cause and to equable temperature conditions, and these combined causes are also effective in giving to the lowlands of the Fraser Valley a high agricultural value.

Table II furnishes comparative data for Victoria (Vancouver Island), Prince Rupert (northern coast), and Kamloops (interior plateau region).

PART II

GEOLOGY

CHAPTER III

FIELD WORK

The vicinity of Vancouver had been visited and examined by numerous geologists before the preparation of this report, and the rocks, especially the Puget formation, had been reported on by several of them. Richardson, in the *Report of Progress of the Geological Survey*, 1876–77, gives brief notes on the character of the Tertiary rocks and the journal of a bore which was made to prospect for coal and reached a depth of 466 feet.

Bauerman, in his report on the forty-ninth parallel west of the Rocky Mountains,[1] describes the country from Semiahmo Bay to Sumas Lake as flat and swampy and consisting of bowlder clay overlaid with coarse gravels in broad flat terraces.

In 1887 Mr. Amos Bowman examined the region from the international boundary to Burrard Inlet with a view to the discovery of coal. He estimated the thickness of the strata exposed on Burrard Peninsula at 3,000 feet.[2]

With the exception of occasional assays of samples submitted to them the Geological Survey did no further work on this field until 1906, but in 1890 G. M. Dawson published a short note on the Puget formation,[3] and in 1896 Sir J. W. Dawson wrote his valuable paper on the fossil flora contained in the Puget beds.[4]

In 1906 O. E. LeRoy made a careful reconnaissance of the coast line and islands from the international boundary to the north of Powell River, with especial attention to economic considerations, and his report is at present the standard authority for the region.[5]

Much valuable information has been obtained during the last few years through the efforts of the British Columbia Mountaineering Club, and special reference should be made to the papers published in the

[1] *Geol. Surv. Canada*, 1882–84, p. 10 B. [2] *Ibid.*, 1887–88, p. 66 A.

[3] G. M. Dawson, *American Journal of Science*, 3d Ser., XXXIX (1890), 180.

[4] Sir J. W. Dawson, *Transactions and Proceedings of the Royal Society of Canada*, 1895, Vol. I, sec. 4, pp. 137–51.

[5] O. E. LeRoy, *Geol. Surv. Canada*, *Publication 996*, 1908, "Preliminary Report on a Portion of the Main Coast of British Columbia and Adjacent Islands, Included in New Westminster and Nanaimo Districts."

TABLE III

GEOLOGICAL TABLE

	Age	Formation	Processes	Locality	Physiographic stage
	Recent	Alluvial and delta deposits at or near present sea level	Uplift, followed by stream cutting in drift and rock valleys with marine and alluvial deposition	Fraser Delta Capilano Delta Lynn Seymour Delta, Capilano, Lynn, and Seymour canyons Cheakamous Canyon Highlands	Stehekin stage
Pleistocene		Raised deltas Garibaldi lavas			
		Unconformity	Vulcanism		
	Wisconsin (?)	Outwash Vashon till	Recession of ice Glaciation subsidence	Lowlands and highlands	Chelan stage
	Interglacial	Puyallup unconformity Admiralty sediments: Clays, Sands	Uplift and erosion Glacial recession and marine deposition subsidence		
	Older glaciation	Admiralty till Nikomekl silts	Glaciation	Lowlands and mountain valleys	
	?Late Pliocene		Canyon cutting uplift	Highlands	Twisp stage
			Glaciation ? Mature erosion Uplift	Highlands	Entiat stage
			Planation	Highlands and lowlands	Methow stage *

Post-Eocene (Miocene or Pleistocene)	Black Tusk basalts	Vulcanism	Garibaldi region Vancouver (Stanley Park and Fairview)	Post Methow* in Pleistocene
Eocene	Intrusive contact			
	Puget formation conglomerate Sandstone and shale (4500′)	Estuarine and subaerial deposition	Burrard Inlet south to boundary	
Cretaceous Comanchean	Erosional unconformity	Denudation of batholith	Highland	
Upper Jurassic	Coast batholiths Diorite	Igneous intrusion	Highland	
	Intrusive contact			
Triassic?	Porphyrites (Valdez)			
	Intrusive contact	Intrusion into Palaeozoic rocks	Mount Strahan? Capilano Valley	
?	Britannia conglomerate quartzite, slate Unconformity	Marine deposition Sea advance Uplift and erosion	Mount Brunswick	
Devono-Carboniferous	Texadan limestones schist, basic igneous rocks, cherts	Marine deposition Vulcanism	Mount Strahan Black Mountain Caulfields Lynn Valley Seymour Ridge	

* If the Black Tusk basalts are early Pleistocene (see pp. [illegible]), the Methow should be placed below them in this table.

Northern Cordilleran by C. J. Heany on "The Topography of the Vancouver or Britannia Range" and by J. Porter on "Geological Features of the Coast Range." Both deal specifically with the mountain section of the area discussed in this paper, and Heany's paper is accompanied by a useful topographic map.

The field work for the present report was begun during the writer's residence in New Westminster from 1905 to 1910, when the glacial deposits from the boundary along the coast to Burrard Inlet were examined. The work on the mountain section was done during the summers of 1913 and 1914. Traverses were in general carried up the valleys of the streams, and, where necessary, over or along the intervening mountain spurs. A week was spent in the very interesting region near Mount Garibaldi, where the opportunity was afforded of comparing the physiographic and stratigraphic features in the central part of the range with those near its edge. Care was taken in defining the inland boundaries of the various Paleozoic areas which had been previously examined only along the shore line, and a few new areas were mapped.

Some further attention was also paid to the lowland, especially the terraces on the north side of Burrard Inlet and the raised deltas at the mouths of the Capilano, Lynn, and Seymour creeks.

The writer's sincere thanks are due to numerous members of the engineering profession and others who have assisted by furnishing maps or other information. Among many who might be mentioned, Messrs. Herman and Burwell, the Scott-Goldie Quarry Company, Mr. Creer of the Burrard Joint Drainage Committee, Mr. James Porter and others of the City Engineer's Office, and the management and members of the British Columbia Mountaineering Club deserve special thanks.

The various formations present in the area which was examined are indicated in Table III, together with an outline of their interpretation.

CHAPTER IV

THE PALEOZOIC

The Devono-Carboniferous rocks of this region have been divided by LeRoy into three formations, to which he has given the names Texada, Britannia, and Marble Bay in ascending order. The entire group seems to correspond with Dawson's Cache Creek group of the interior plateau, the upper member of which (the Marble Canyon) is a *Fusulina* limestone of Pennsylvanian age. Some uncertainty exists as to the relations of the Marble Bay to the Britannia, but both are younger than the Texadan, and the occurrence of chert, as well as general lithological resemblances and stratigraphic position, suggest that the Texadan is the coast equivalent of Dawson's Lower Cache Creek group in the interior. The Marble Bay formation occurs on Texada Island, but not within the area covered by the present paper.

The Paleozoic rocks in all cases overlie the younger Coast Batholith, which everywhere intrudes them from beneath. Typical instances of brecciated contact-zones and apophyses of the batholith penetrating the older rocks are to be seen in all the observed areas, and will be dealt with more fully under the discussion of the batholith itself. Contact metamorphism of the Paleozoics, including the development of metallic ores along their margins and within their mass, renders these areas of great economic interest. It can also be more appropriately treated after some consideration of the intrusive rocks to whose presence it is due.

THE TEXADA FORMATION

The Texadan is described by LeRoy as consisting of a great variety of meta-igneous rocks "forming a great basic complex, along with a few interstratified and now highly altered sediments. The rocks are agglomerates, breccias, tuffs, porphyrites, diabases, lavas, schist, slate, chert, and crystalline limestones. Conditions of vigorous volcanic activity must have alternated with quieter periods, when true sediments interbedded with tufaceous ash rocks were deposited in local and separated basins."[1]

[1] *Geol. Surv. Canada, Publication 996*, 1908, p. 13.

The areas of Texadan rock which have been mapped in the region between Howe Sound and the North Arm of Burrard Inlet are the following:

1. *Black Mountain area.*—A small area of crystalline schist is exposed along the east shore of Howe Sound commencing a short distance north of Horseshoe Bay and extending about two miles northward along the shore, and inland up the side of Black Mountain to an elevation of about 1,700 feet. The rocks are schistose and gneissoid representatives of the igneous Texadan rocks and have a strike varying from 85° to 110° east of north with northerly dip from 60° to nearly vertical. So fa. as its boundary was explored, very little evidence of metasomatic replacement was observed. This is probably due to the fact that the rocks are not of such composition as to furnish elements capable of precipitating the metallic elements furnished by the hydrothermal action of the batholith. The rock as studied is for the most part mica-schist.

2. *Caulfields area.*—On the point east of Caulfields there is a small area containing a few acres of Paleozoic schist, probably to be referred to the Texadan. The general strike of the schistosity here is 128°, and the dip northeasterly, 61°—which corresponds very closely with the strike and dip of the same formation in the Black Mountain area. The schist is here intruded by a basic porphyrite which is older than the Coast Batholith, and which may be of Triassic age. Both schist and porphyrite are traversed by apophyses from the batholith, and both the batholith and the Paleozoic rocks are cut by dikes of diorite porphyry.

3. *Mount Strahan area.*—The rounded summit of Mount Strahan and of the domelike mountain which overlooks the Capilano Valley about a mile southeast of Mount Strahan are composed of Texadan rocks. The Texadan area also extends some distance south along the higher terraces of the ridge which lies on the west side of the Capilano Valley (Hollyburn Ridge), and northward from Mount Strahan along the eastern slope of Timber Mountain, which overlooks Sisters' Creek. The total length of the area in a direction about 15° west of north is nearly three miles, while the maximum distance from east to west is one and two-thirds miles. The rock is for the most part mica-schist, which has a strike of from 100° to 110° where observed, and dips almost vertically. It is brecciated and intruded along the planes of schistosity by apophyses from the batholith. Near the contact with the batholith at the southern end of the area, and on the small creek which flows down on the east side of Mount Strahan to Sisters' Creek, there is a dark-green massive porphyrite with phenocrysts of white plagioclase, hornblende laths, and

some magnetite grains in a dark-gray or greenish matrix. Microscopically this rock consists of phenocrysts of andesine, which occupy most of the field in the section examined and are included in a groundmass which is hypautomorphic-granular in texture and consists of andesine laths with hornblende and some magnetite in the interstices between the feldspars. Secondary epidote, quartz, and hematite are also present in the rock where it is seen in the bed of the creek east of Mount Strahan. This rock appears to be intrusive in the mica-schist, and to be itself intruded by the lighter-colored diorite of the Upper Jurassic batholith. A small area of similar rock also occurs at the intake of the Vancouver waterworks in the Capilano Valley.

The lower surface of the Texadan rocks varies in elevation from 3,500 feet at the southern end of the Mount Strahan area to about 1,000 feet in the valley east of Mount Strahan. It appears to be of somewhat irregular form, but with rounded rather than angular changes of direction. The strike and dip here correspond closely with those of the Black Mountain and Caulfields areas, and the inference seems clear: (1) The three areas are parts of a formerly continuous terrain, and still retain their original relative positions. They undoubtedly formed part of the batholith roof which has been separated by subsequent erosion into the present isolated areas. (2) The close folding which is represented by the present attitude and schistosity of the rocks took place prior to the intrusion of the Upper Jurassic batholith, and prior also to the earlier intrusion described above, which may be Triassic in age.[1] The diastrophism must have been post-Pennsylvanian, if we place the Britannia in that period, since the Britannia rocks are involved in the folding. Bancroft also finds Triassic rocks at Queen Charlotte Sound but little folded.[2] The deformation may therefore be assigned with some probability to the uplift of Permo-Carboniferous time. If this is correct, it appears that the Coast Range probably originated at this time. The strike of the schists is nearly parallel to the axis of the range at this point, which would agree with the hypothesis that the axis of the orogenic movement and the direction of lateral pressure were nearly the same as in later periods.

4. *The Mount Brunswick area.*—Commencing at a point on the east side of Howe Sound two and one-half miles north of the northern end of the Black Mountain Texadan area, Texadan rocks are again exposed along the shore as far as the Montagu Channel, where they give way to

[1] See discussion of Triassic on p. 42.

[2] J. A. Bancroft, *Geol. Surv. Canada, Memoir 23*, p. 60.

the Britannia formation. The area, as mapped by LeRoy, is a narrow strip which nowhere has sufficient extension inland to reach the summit of the spur which parallels the fiord, but it probably extends inland beneath the Britannia formation at Mount Brunswick. The rocks exposed are of massive meta-igneous type, dark, greenish-gray in color, and much broken up by joints. They have been worn into sea caves at several points along the strand line.

Under the microscope the rock possesses a fine-grained groundmass of feldspar and secondary quartz with a little magnetite, secondary hematite, epidote, and kaolin, and considerable areas of calcite. The outlines of some phenocrysts, apparently plagioclases, are discernible, completely replaced by epidote; in other cases irregular areas of epidote and calcite seem to represent aggregates. Zoisite is also present. According to LeRoy the essential minerals usually present are labradorite, hornblende, and augite. None of these were recognized in the section examined.

On Mount Brunswick the Texadan is overlaid by the Britannia slate and quartzite, which probably extend thence northwesterly to the shore of Montagu Channel.

5. *Lynn Creek area.*—Much of the amphitheater south of Palisade Ridge, which forms the catchment basin of the upper waters of Lynn Creek, is underlaid by Texadan rocks. The area has a northwest and southeast elongation of about four miles, and a maximum width, at right angles to this, of less than a mile and a half. The southeastern extremity of this belt lies upon the summit of Lynn Ridge, between Lynn and Seymour creeks, nearly due west of Mount Seymour. Thence the southwestern boundary of the area runs northwesterly across the Lynn Valley and the northeastern spur of Goat Mountain to Palisade Ridge. It extends over the ridge and for a short distance down the Capilano slope, which it follows northeasterly for more than a mile, and, returning southeast across the Palisade Ridge, crosses Lynn Lake and the east fork of Lynn Creek, and passes over the Lynn Ridge and along its eastern slope to the southerly point of the area.

The rocks, as described by LeRoy, include "massive and banded silicious, epidote and chlorite schists." So far as examined by the writer, they consist of andesite, hornblende diabase, quartz-actinolite schist, hornblende-epidote schist, epidote schist, carbonaceous slate, crystalline limestone, and a calcite-epidote-garnet rock probably due to the alteration of limestone by hydrothermal action following the intrusion of the batholith. There is also a variety of ores, especially of zinc, lead, and

copper, which are undoubtedly to be ascribed to the same source. They occur for the most part in the immediate vicinity of, or in contact with, lenticular beds of crystalline limestone, and are to be considered as of metasomatic origin, inasmuch as they represent a chemical reaction resulting in a replacement of calcium carbonate by various metallic sulphides and silicates. Their formation will be discussed later.

A noteworthy occurrence, not previously reported from the district, is that of the mineral *brucite* ($Mg(OH)_2$), which was observed in a crystalline limestone[1] near the contact of the batholith on the western slope of Lynn Ridge.

6. *The Seymour Ridge area.*—Texadan rocks were mapped by LeRoy extending along the western shore of the North Arm of Burrard Inlet for a distance of two miles, commencing at a point about four miles from the junction with the main inlet. Exploration undertaken during the preparation of the present paper shows that the Texadan area extends across the ridge westward for more than three miles to the edge of the Seymour Valley. The boundaries of the area have not been traced in detail owing to the presence of drift on the southern part of the Seymour spur. The northern limit is just to the north of the most southerly of the summits that rise above the Entiat terraces of the ridge, and culminate to the northward in Mount Seymour. To this summit the name Pump Peak has been given. The general outline of the area seems to be roughly oblong with a small southerly extension at the western end.

The rocks composing this area are entirely volcanic in origin, and are arranged in a syncline of very gentle folding whose structure can be easily understood from Fig. 3. The lower member is a thick flow of massive basalt, which has been quarried by the Scott-Goldie Quarry Company Limited, on the North Arm. Microscopically the rock is a porphyrite which consists of a groundmass of plagioclase laths of varying size with numerous interspersed grains of magnetite. Some alteration of the feldspar to kaolin and sericite is apparent, and is localized in spots which form small pits on broken surfaces of the rock, simulating a vesicular structure. The phenocrysts are: (1) labradorite, in lath-shaped individuals, generally not terminated, and in many cases very irregular in outline; (2) titaniferous magnetite in fairly large grains, which has developed some secondary leucoxene; and (3) augite in well-formed individuals which are in many cases completely altered to chlorite. Small veinlets of epidote traverse the rock, and along their margins areas of calcite occur. There are also separate masses of epidote. The

[1] Tschermak, *Mineralogische und petrographische Mitteilungen*, XII (1892), 429.

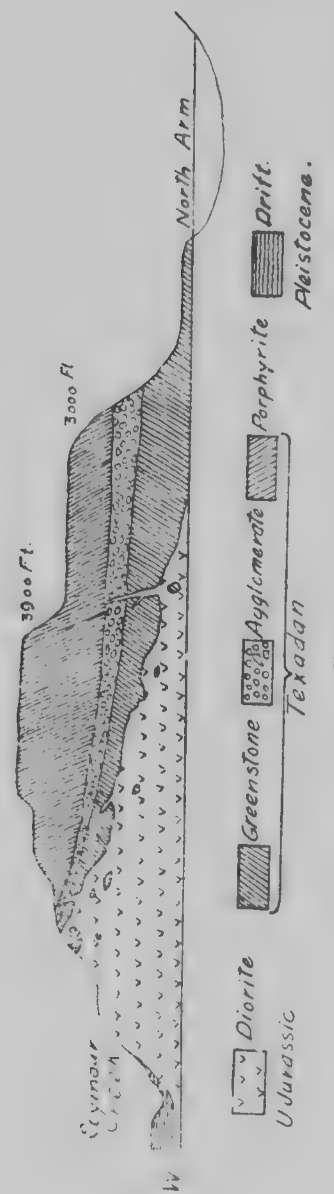


FIG. 3

presence of epidote and chlorite gives the rock a green tint. This is due largely to the alteration of the augite, as the feldspars are on the whole comparatively little altered. No quartz was seen in the section examined.

At an altitude of 1,200 feet above the sea, on the North Arm side of the spur, the greenstone porphyrite is overlaid by a bed of agglomerate, the top of which is about 500 feet higher up. This bed consists of bowlders up to three or four feet in diameter, mostly rounded but partly subangular. The bowlders, especially the larger ones, are of greenstone or porphyrite. A few small angular fragments of chert also were seen. This bed rises toward the north and forms the northern boundary of the area, where it is seen in eruptive contact with the diorite of the batholith at an altitude of over 4,000 feet. On both sides of the contact spherulites of epidote are developed, some of which have a diameter as great as two inches. They consist of radiating fibers of the mineral mostly light yellowish on the outside, but darker in the center, with a little interstitial quartz and magnetite. The matrix of the agglomerate is a porphyrite which has phenocrysts of labradorite and epidote (which probably replaces hornblende or augite). The groundmass is partly dark between crossed nicols, but consists mainly of plagioclase microliths and grains or small aggregates of titaniferous magnetite. The latter is largely altered to

leucoxene and limonite. Some kaolin is present from the feldspar and also grains of pistacite. The bowlders, several of which were examined, are andesite and basalt, in most cases much altered. They probably represent lower members of the Texadan group. They have become involved in a subsequent flow in such numbers as to resemble a conglomerate. The bowlders or smaller pebbles often weather out, leaving intervening parts of the groundmass standing in relief on the surface of the rock.

Above the bed last described the summit of the ridge is composed of a thick bed of greenstone porphyry whose precise nature is not always easily determined, owing to extensive alteration. The groundmass consists of highly kaolinized feldspar microliths and magnetite grains containing badly decomposed plagioclase phenocrysts and masses of quartz and epidote which probably represent other phenocrysts. Titaniferous magnetite with secondary leucoxene and areas of calcite are also present. The whole may have been anywhere between andesite and basalt.

On the side facing Seymour Creek the stoping of the lower porphyrite by the batholith is well shown by the very large inclusions, some of them at least 200 feet long, which are found submerged in the batholith several hundred feet below the contact, and of course some distance from it horizontally. These were by far the largest xenoliths observed in the area examined.

7. *The Garibaldi region.*—The western part of the base of Black Tusk Mountain consists of massive greenstone of considerable thickness, which appears to be much altered, and sheared andesite or diorite porphyrite, and basalt, with impure crystalline limestone containing magnetite. These rocks dip steeply to the eastward.

THE BRITANNIA FORMATION

Rocks of this formation occur within the area examined only on the upper part of Mount Brunswick, where they are represented by black fissile and somewhat ferruginous slates, interbedded with igneous flows or sills which are now altered to quartz-epidote schist, consisting of angular fragments of quartz and oligoclase-andesine, with epidote which fills spaces between the fragments. These larger elements are imbedded in a finer groundmass of the same materials with titaniferous magnetite grains from which leucoxene has developed as an alteration product. The igneous rock is therefore a sheared quartz-andesite. In a less altered case chlorite is also present, representing the original ferromagnesian

constituents, but these seem to have been small in amount or else their constituents have been largely removed in the process of katamorphism. In the same section the quartz phenocrysts are fairly entire and exhibit erosion. The rock is therefore probably an acid end-phase of a dioritic intrusion. At the upper part of the series are some hundreds of feet of thick-bedded quartzite, while at the base, on the south end of an even-topped spur which extends southward from the east end of Mount Brunswick, there is a small remnant of a basal conglomerate, consisting of pebbles which, to a large extent, represent the Texadan rocks.

The total thickness of the series as exposed on Mount Brunswick was not accurately measured, but was estimated at 4,000 feet, arranged as follows:

4. Thick-bedded quartzite or sandstone	500 feet
3. Interbedded slate and sheared porphyrite	2,000 feet
2. Massive porphyrite, not sheared	1,500 feet
1. Basal conglomerate	20 feet

As the conglomerate was not seen in contact with the lower massive porphyrite, it is possible that the massive porphyrite should be eliminated from the series, as being possibly Texadan or a Triassic intrusion. The whole formation has a general strike of about N. 5° W., and a dip to the westward of 47° where measured. The strike is transverse to the wedgelike ridge of the mountain, which runs east and west and has an elevation of nearly 6,000 feet, the highest in the Vancouver Mountains.

In the Garibaldi region the eastern part of the base of Black Tusk Mountain and Panorama and Helmet ridges exhibit a fine section of the Britannia formation, which, as measured along the exposure, has a thickness of over 6,000 feet. It consists of a basal conglomerate which lies upon the Texadan beneath, and is followed by quartzite with interstratified conglomerate, which in turn gives way to slates with interstratified igneous beds and, at the summit of the section, quartzite. These two sections, apart from the thick porphyrite at the base on Mount Brunswick, are quite similar. The strike of the Panorama Ridge section is about N. 30° W., and the dip eastward from 0° to 60.°

In this section many of the pebbles of the basal conglomerate are granitic, and LeRoy mentions the same fact observed at Britannia Beach on Howe Sound.[1] He also describes the quartzite as containing orthoclase and biotite, which with quartz form the constituents of granite, and says that some of the granite pebbles at Britannia Beach are large—a fact which was not observed in the places examined by the writer. All

[1] O. E. LeRoy, *Geol. Surv. Canada, Publication 996*, p. 15.

of these facts indicate clearly that there was in the Devono-Carboniferous a source of granite débris near at hand, since transportation for any but a limited distance must have resulted in kaolinization of the feldspars and sorting of the materials. On the other hand, the slates somewhat higher in the series would appear to indicate that at a later period there were quiet-water conditions in which sorting took place, and clays were laid down, while the quartzites at the top imply a return to shallow water or subaërial deposition. The problem of the granite pebbles also occurs in rocks of similar age in the Coast Range of California, and it has been suggested that there was at that time an Archaean axis above sea-level to the west of the present coast line.[1] If that explanation were adopted here, we should have to look to land west of Vancouver Island or to land occupying the line of the present depression between the coast and islands. There may also have been a core of older granite in the Coast Range itself.[2] There remains the possibility of a glacial explanation, whereby the transportation of the materials, without sorting even from the Archaean axis of the Gold Ranges, might be accounted for, but no specific evidence of this from the deposits themselves has yet been adduced.[3]

The Britannia slates are very important for the extensive replacement deposits of copper and gold ores which they contain, in the area which lies to the north of Mount Brunswick on the east side of Howe Sound. These were not examined by the writer, and can therefore be only referred to here. The ore minerals are pyrite, chalcopyrite, and galena, with a little bornite and covellite as secondary enrichment. Silver and gold also are present. The metalliferous minerals occur in sericite schist.[4] The ore deposit ceases abruptly at the contact of carbonaceous slates, and the development of the sericite seems to have been contemporary with the mineralization.[5] Little has yet been done in tracing the chemical side of the ore-genesis.

[1] T. C. Chamberlin, private communication.

[2] Compare Daly's description of the Custer granite-gneiss in the Skagit Range, *Geol. Surv. Canada, Memoir 38*, Part I, p. 507.

[3] O. E. LeRoy, *op. cit.*, p. 15.

[4] *Ibid.*, p. 33.

[5] *Ibid.*, p. 31.

CHAPTER V

THE POST-PALEOZOIC (TRIASSIC?) PORPHYRITES

It is possible that the dark green and gray porphyrites of Mount Strahan, which are intruded into the Texadan schist but are themselves unfoliated, may be of Carboniferous age, and might be placed in the Texadan, which LeRoy describes as a complex, since their relationship with the more schistose rocks is very difficult to work out in detail, and there are in many parts of the Texadan series massive porphyrites of almost the same appearance which are undoubtedly contemporaneous. Nevertheless it appears that the lack of foliation in rocks which intrude schists must be taken as evidence that they were so intruded after the development of the schistosity. Since, then, the probability is that the movement which produced the schistosity occurred in the Permian period, the age of this porphyrite, which is older than the Upper Jurassic batholith, and is very similar to the Triassic igneous rocks of the Vancouver group of Dawson, is probably Triassic, and it is then to be regarded as representing a part of the great igneous activity which at that time[1] affected the Vancouver Island area and the marginal islands of the Coast Range in the Queen Charlotte Sound region.[2] It may indeed be urged that the greater competence of the porphyrite has prevented the development of schistosity in it, but the sharp nature of the intrusive contact between the schist and the porphyrite seems clearly to contradict such a hypothesis. Like the Triassic rocks of the regions referred to (1 and 2), these occurred in rounded forms with smooth surfaces, which have the appearance of being polished and suggest great compactness of texture.

The outcrops which could be definitely assigned to this series occur in the valley of a small stream on the eastern side of Mount Strahan. One of the specimens which was examined from that locality shows a groundmass of fine granular feldspars with epidote and pyrite grains in which are large phenocrysts of oligoclase or andesine, the determination of which is difficult, owing to the fact that they are largely replaced by kaolin and epidote. There are large grains of titaniferous magnetite

[1] G. M. Dawson, *Geol. Surv. Canada.*

[2] J. A. Bancroft, *Geol. Surv. Canada, Memoir 23* (1913), p. 68.

with secondary leucoxene. In another specimen the groundmass contains quartz, titaniferous magnetite, and hornblende, with secondary leucoxene, chlorite, and epidote, and the phenocrysts are of andesine largely altered to kaolin, hornblende largely chloritized and associated with much epidote, and titaniferous magnetite. Some calcite and zeolite are also present. This agrees very well with Bancroft's description of the Valdez andesite from the Queen Charlotte Sound, except that hornblende here replaced augite as the chief ferromagnesian constituent. This also occurs in the region described by Bancroft near the contact with the Coast Batholith, which is the position of the specimens from Mount Strahan.

A small isolated area which may be of these rocks occurs at the intake of the Vancouver waterworks on Capilano Creek.

CHAPTER VI

UPPER JURASSIC (?)

THE COAST BATHOLITH

After the deposition and folding of the Devono-Carboniferous rocks and the subsequent intrusion and extrusion of Triassic andesites and basalts, the next event of great importance in this locality was the intrusion of the immense series of predominantly dioritic batholiths which extends from the Fraser River in a northwesterly direction into the Yukon territory. While precise determination of the time at which this intrusion took place has not as yet been made, it appears that the Nicola series, the upper part of which, as exposed near Spatsum, is Lower Jurassic,[1] was subjected to some folding before being intruded by offshoots of the Coast Batholith. This would make the date of the intrusion not earlier than late Jurassic. The nature of the contact between the granite rocks and the Nicola is not made clear, however. On the western margin of the batholith the Triassic formations are also intruded,[2] while the Cretaceous (Chico) sediments are partly derived from the eroded batholith.[3] The intrusion was therefore pre-Cretaceous. The evidence available in the vicinity of Vancouver shows that the batholith had been deeply eroded before the basal Eocene deposits were laid down. It appears that the intrusion of the batholith took place in successive movements[4] with some intervals of quiescence between, at least as regards any given locality, since basic marginal differentiation phases of it are found intruded by more acid apophyses. In the area included in this report the evidence of such action is not conclusive, nor does it appear that more than one local batholith is concerned.

Rocks.—In this region the batholith, as elsewhere, presents a uniformly coarse granular texture, which is varied, however, near intrusive contacts, by gneissoid texture due, so far as seen here, to movement of the fluid mass before cooling. This gneissoid phase was observed in the

[1] G. M. Dawson, *Geol. Surv. Canada*, N.S., VII (1894), 112–13 B.

[2] J. A. Bancroft, *Geol. Surv. Canada, Memoir 23*, 1913, p. 106, and G. M. Dawson, *Geol. Surv. Canada, Ann. Rep.*, 1886, Part B., p. 11.

[3] O. E. LeRoy, *Geol. Surv. Canada, Publication* [illegible], pp. 18, 23.

[4] *Ibid.*, p. 104.

Cheakamous Valley in exposures along the road which has been lately built as an aid to railroad construction. In the valley of the east branch of Capilano River a bowlder was observed derived from the batholith which was filled with orbicular bodies averaging 6 or more inches in diameter. They consisted of central masses of very coarse granular rock, without symmetrical arrangement of constituents, surrounded by successive bands of rock minerals, arranged radially as regards mineral individuals. Between the orbules the rock was hypautomorphic granular, of decidedly finer grain than that in the center of the orbules.

The mineralogical composition of the rocks, of which the prevailing type is a quartz-diorite, is indicated in the accompanying tables and diagram, which are based on measurements, made by the Rosiwal method, of samples which represent fairly well-spaced positions throughout the area and also special differentiation. The localities from which the samples examined were taken are as follows:

A. Keith Road, at stream, one mile west of Dundarave; quartz-mica diorite.
B. West side of Point Atkinson; quartz-diorite with accessory titanite.
C. Bay between Caulfields and Cypress Creek on shore; quartz-diorite.
D. Shore northward of Eagle Harbour, on Howe Sound; hornblende diabase—a marginal differentiation phase.
E. Near Paleozoic contact on Mount Strahan; diorite high in hornblende.
F. Quarry, south face of Dome Mountain, North, Vancouver; quartz-diorite.
G. Junction of Capilano and Sisters' creeks; quartz-diorite.
H. Seymour Canyon; a very quartzose phase of quartz-mica diorite.
I. Lynn Valley zinc mine—Kemptville claim near Texadan contact; diorite, little quartz, and much hornblende.
J. Seymour Creek Falls; quartz-diorite.
K. Half a mile northwest of Wigwam Inn, on the Indian River trail; quartz-diorite—very low in ferromagnesian constituents.
L. Top of Castle Towers Mountain (Mount Garibaldi region); quartz-biotite diorite.

EXPLANATION OF DIAGRAM

The angular points of the large triangle represent 100 per cent of the constituents whose name they bear.

The sides of the small triangles represent by their position the percentage of quartz, feldspar, or ferromagnesian minerals that the rock contains, counting from the parallel side of the large triangle.

The length of sides of the small triangles represents the percentage of accessories (black) and alteration products (white). The kaolin is not represented in the secondary minerals owing to the difficulty of estimating it by the Rosiwal method, but its amount is indicated in the table as large (L),

medium (M), or small (S) in proportion to the amount of feldspar. The secondary minerals indicated by space in the small triangles are chiefly epidote (with some chlor'te), so that the size of this space is an indication of the amount of the hydrothermal alteration which the rock has undergone.

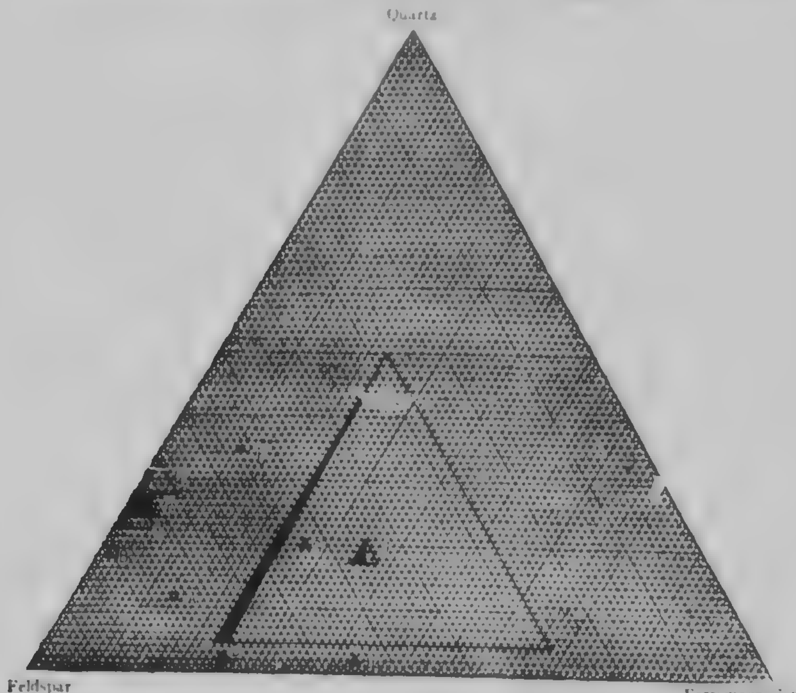


FIG. 4.—Specimens of the Coast Batholith. Diagram of mineralogical composition

Black represents accessories
White, secondary minerals

The minerals observed in thin sections were:

Primary		Secondary
Essential	Accessory	
Orthoclase	Quartz	Epidote
Oligoclase[1]	Magnetite	Chlorite
Andesine	Apatite	Sericite
Labradorite	Titaniferous magnetite	Kaolin
Bytownite	Augite	Hematite
Hornblende	Tourmaline	Leucoxene
Biotite	Titanite	Calcite
(Augite)		

[1] The plagioclase is in many cases untwinned.

TABLE IV

MINERALOGICAL COMPOSITION OF COAST BATHOLITH TYPES

(Volumetric, Rosiwal method)

		A	B	C	D	E	F	G	H	I	J	K	L
Texture		Granular	Granular	Granular	Ophitic	Granular	Granular	Granular	Granular	Granular	Granular	Granular	Granular
Feldspar plagio-clase	Comp.	Ab An	Ab An	Ab An	Ab An	Ab An	Ab An	Ab An	Ab An	Ab An	Ab An	Ab An	Ab An
	Percen-tage.	50 50	70 30	60 40	50 50	60 40	65 35	55 45	67 33	50 50	55 45	55 45	50 50
		74.41	79.07	72.24	72.91	27.14	54.45	52.83	66.70	54.73	44.61	[illegible]	63.03
(Orthoclase)		P	. .	. .			P						P
Hornblende		3.81	1.39	0.32	24.74	22.71	10.22	24.59	0.52	42.98	34.53	1.3	15.78
Biotite		9.81	.		. .			2.12	.				0.84
Quartz		11.04	17.57	22.34	1.35	4.04	34.28	19.66	27.3	1.34	[illegible]	24.01	[illegible]
Titanite			0.31	0.37	.								
Magnetite		0.53	0.29	0.55	1.30	1.32	0.32	0.12	0.91	[illegible]	1.40	3.4	0.44
Apatite		0.065	. . . .	. .	. . .	0.22	0.32	0.03		0.10			0.05
Secondary minerals													
Epidote		. . . . .	0.21	2.10	0.20	43.09	0.23	0.56	4.11	0.02	[illegible]	[illegible]	[illegible]
Calcite		.	. .	. . .	. . .		0.18	.	0.45			[illegible]	
Sericite		.			.	0.06							
Kaolin		S	M	M	S	M	L-M	S-M	L	M	M-L	S	S
Chlorite		0.4	0.54	2.02					1.11				[illegible]
Total		100.065	99.98	100.00	100.50	99.78	100.00	99.91	101.16	100.02	100.01	100.52	100.22

TABLE V

CHEMICAL COMPOSITION

(For Modes, see page 47)

Chemical Composition	A	B	C	D	E	F	G	H	I	J	K	L
SiO_2	60.80	69.292	69.11	55.81	58.12	72.80	63.875	77.55	53.26	60.13	65.789	58.88
Al_2O_3	20.96	18.304	18.03	20.58	18.84	13.76	15.79	16.44	17.62	14.62	17.292	19.15
Fe_2O_3	1.04	0.515	0.88	2.54	3.07	1.03	1.68	1.29	3.61	3.944	4.49	1.55
FeO	1.36	0.43	0.63	3.48	3.51	1.48	3.20	0.75	5.50	4.973	2.142	2.77
CaO	8.27	3.35	4.35	8.31	6.86	4.065	7.101	3.40	9.425	7.393	4.422	9.0124
MgO	0.57	0.27	0.32	3.25	2.98	1.38	3.24	0.22	5.47	4.45	0.17	2.16
K_2O	0.95	0.02	0.03	0.24	0.22	0.26	0.43	0.02	0.41	0.33	0.013	1.22
Na_2O	5.84	7.654	0.46	5.79	6.28	5.01	4.64	4.22	4.60	4.16	5.682	5.06
TiO_2		0.165	0.19	...	...	...	...	...	...	...	...	
P_2O_5	0.034	...	...	...	0.11	0.16	0.013	...	0.046	...	...	0.0
F	0.173	...	...	...	0.01	0.015	0.031	...	0.004	...	...	0.1[illegible]
Total	100.000	100.00	100.00	100.00	100.00	100.000	100.000	100.00	100.[illegible]	100.000	100.000	100.00

TABLE VI

Norms

Minerals	A	B	C	D	E	F	G	H	I	J	K	L
Quartz	7.12	17.52	21.72	.	2.61	32.48	16.17	26.376		13.02	22.82	4.19
Orthoclase	5.56	0.1112	0.17	1.39	1.28	1.67	2.78	0.111	2.45	2.22	0.08	7.23
Albite	40.26	64.452	54.50	48.73	51.92	42.44	39.30	55.020	38.88	35.11	48.21	44.02
Anorthite	28.08	15.51	20.21	29.52	22.71	14.18	20.85	15.510	25.80	20.02	21.64	25.30
Diopside	6.02	0.9232	1.62	9.41	8.62	3.99	11.47	0.497	16.48	13.50	0.20	14.50
Hypersthene		0.396	0.28	5.53	7.18	3.31	6.96	0.624	5.39	10.36	0.53	1.90
Olivine	.	...	...	1.62			...	...	5.44	......		..
Wollastonite	1.76	...										
Ilmenite		0.304	0.3							.....	..	..
Magnetite	1.51	0.696	1.28	3.71	4.41	1.62	2.44	1.856	5.24	5.80	6.52	2.25
Apatite	0.07			.	0.22	0.34	0.03		0.09	.		0.06
Fluorite	0.34	....	.		0.02	0.03	0.06	..	0.01	..	.	0.40
Total	99.74	99.9124	100.08	99.91	98.97	100.06	100.06	99.994	99.78	100.03	100.06	99.85

Classification

	A	B	C	D	E	F
Class	1 Persalane	1 Persalane	1. Persalane	1. Dosalane	2 Dosalane	1 Persalane
Subclass	1 Persalone	1 Persalone	1 Persalone	1 Dosalone	1 Dosalone	1 Persalone
Order	5 Perfelic (Canadare)	4 Quardofelic (Britannare)	4. Quardofelic (Britannare)	5. Perfelic (Germanare)	5. Perfelic (Germanare)	4 Quardofelic (Britannare)
Rang	3. Alkalicalcic	3. Alkalicalcic (Coloradase)	3 Alkalicalcic (Coloradase)	3. Alkalicalcic (Andase)	3 Alkalicalcic (Andase)	3 Alkalicalcic (Coloradase)
Subrang	5. Persodic	5. Persodic	5. Persodic	5. Persodic	5 Persodic	5 Persodic
Name	Unnamed	Amadorose	Amadorose	Beerbachose	Beerbachose	Amadorose (close to Mariposose)

	G	H	I	J	K	L
Class	2. Dosalane	1. Persalane	2 Dosalane	2. Dosalane	1 Persalane	2. Dosalane
Subclass	1 Dosalone	1. Persalone	1. Dosalone	1. Dosalone	2 Persalone	1 Dosalone
Order	4. Quardofelic (Austrare)	4 Quardofelic (Britannare)	5. Perfelic (Germanare)	4 Quardofelic (Austrareic)	4. Quardofelic (Britannare)	5. Perfelic (Germanare)
Rang	3. Alkalicalcic (Tonalase)	2. Domalkalic (Toscanase)	3. Alkalicalcic (Andase)	3. Alkalicalcic (Tonalase)	3 Alkalicalcic (Coloradase)	3 Alkalicalcic (Andase)
Subrang	5 Persodic	5. Persodic	5. Persodic	5 Persodic	5. Persodic	5 Dosodic
Name	Placerose	Mariposose	Beerbachose	Placerose	Amadorose	Andose (near Beerbachose)

The rock types recognized within the area are:

1. (Biotite granite.)[1] 2. Granodiorite. 3. Quartz andesinite. 4. Quartz-mica-diorite. 5. Quartz-diorite. 6. Diorite. 7. Hornblende diabase. 8. Hornblende gabbro. 9. (Gabbro.)[1]

Of these the quartz-diorite is easily the dominant type for the area under consideration. The more quartzose phases occur at a distance from Paleozoic contacts, and the more basic as the contacts are approached. This marginal differentiation generally takes the form of a decrease in quartz and an increase in hornblende. The appearance of augite, as at Whyte Cliff, is exceptional. In some cases, as in the vicinity of The Lions, the hornblende becomes so predominant that the rock over small areas might be properly described as hornblendite. This type of differentiation occurs in contact with the basic eruptives and limestones of the Texadan series, and where it occurs at a distance from roof remnants it probably indicates that the roof originally existed in close proximity to the remaining differentiation rocks. A prominent case of this sort is that of the peaks known as "The Lions"—two rock towers some 700 feet in height which consist from the base up mainly of hornblende gabbro. They are probably erosion remnants whose survival is due to the original presence, not far above their present summits, of very resistant Texadan rocks in the roof of the batholith. These have now been removed by erosion. The vertical thickness of the differentiation zone must have been at least 800 feet in this instance. In the area from Eagle Harbour northward, where similar rocks are exposed for about two miles, horizontally measured, south of the Paleozoic contact, the roof was probably at no great distance above the present surface. The remnants of it which remain near by, on Bowen Island and in other directions, seem to indicate this.

The apophyses of the batholith penetrate the older rocks in some cases to considerable distances, so that doubt sometimes arises as to their identity. They are in general quite similar in composition to the main batholith, and little evidence of mineralizers was met with beyond an unusual amount of quartz. Pyrite occurs in a dacite which underlies the post-Eocene lavas of Table Mountain, but whose structural relations are obscure. A very good example of the apophyses occurs on the point east of Caulfields. The intrusion is along the schistosity of the Texadan rock and is of pegmatitic texture. Its main constituent is quartz (estimated 65 per cent), with plagioclase ($Ab_{0.85}$, $An_{0.15}$), about 30 per cent. Orthoclase, microperthite, titaniferous magnetite, and rutile

[1] Reported by O. E. LeRoy.

occur as accessories, with a small amount of hornblende. The secondary minerals are kaolin, hematite, and leucoxene. The composition, according to the old classification, would be alaskite pegmatite. In other cases no differentiation is observable in the apophyses.

Subsequent to its cooling, the batholith and its adjacent rocks were intruded by a series of dikes, some of which are of composition very like the average of the batholith itself, while others are much more basic. The age of the latter is doubtful, and, so far as the evidence here goes, they may very well represent either post-Eocene or Pleistocene vulcanism in some cases, but LeRoy states that some at least are pre-Cretaceous.

Of the dioritic dikes very typical examples may be seen penetrating both the batholith and the Texadan schists on the point east of Caulfields. Others, whose lithology has not been determined, occur on Point Atkinson.

The dikes in the shore east of Caulfields Landing are porphyritic in texture, with a granular groundmass of andesine and hornblende, with some magnetite in which are phenocrysts of andesine and hornblende. There is a considerable amount of secondary epidote, sericite, kaolin, and chlorite. Magnetite grains are included in the hornblende.

The dark rocks seen on the southern shoulder of Grouse Mountain are of very similar type, and are also characterized by the skeleton-like hornblende aggregates. They may be either wide dikes or differentiation zones. The appearance of these rocks is darker than that of the batholith in general. Other examples of the same type occur on Lynn Ridge (southeastern corner of Lot 1944) and in the Cheakamous Valley. The magnetite in the latter case is distinctly titaniferous.

Traversing the coarse granular batholith in a variety of directions are aplitic dikes, some of which, where small, are foliated parallel to their length. They are more quartzose than the earlier phases of the batholith. As an example, a quartz-diorite aplite from the northern end of Hollyburn Ridge consists of quartz (about 35 per cent), andesine (50 per cent), and hornblende (15 per cent) in small individuals and stringlike aggregates, with some magnetite grains. A somewhat similar dike which cuts the Paleozoic rocks on Texada Ridge, a short distance southeast of Mount Brunswick, exhibits under the microscope a quartz mosaic with shreds of muscovite and looplike meshes of kaolin (?) between the quartzes. There are small amounts of chlorite and of magnetite which are partly altered to hematite. The whole has undergone sufficient metamorphism to have assumed a schistose structure.

Reticulating in all directions through the batholith, along what often appear to have been planes of faulting, are small veins which consist almost entirely of epidote, with small percentages of quartz and titaniferous magnetite. These become especially numerous near the intrusive contacts and penetrate the Paleozoic rocks in many cases as veins of considerable width. They fault the aplite dikes, to which they are therefore subsequent. In addition to its occurrence in the veins, epidote is widely developed throughout the mass of the diorite, apparently as a secondary product, and forms very noticeable spherulites, which have a diameter as great as two inches, along the contact of the Texadan agglomerate on Seymour Ridge. These consist of radiating fibers of epidote with a little interstitial quartz and magnetite.

The presence of these dikes and veinlets clearly indicates a number of *nachschuben* following the main intrusion at considerable intervals. In some parts of the range[1] there were successive intrusions which assumed the form of further advances of the batholith as a whole, but here the later recrudescences of the igneous advance, which may have coincided with massive movements elsewhere, were confined to the formation of end-product dikes, and finally the hydrothermic action, which produced the epidote veins and replacements. Of these various movements the last seems to have played the most important part in the contact metamorphism and mineralization of the intruded rocks.

Shattered contact-zones are usually present. Though not everywhere marked, they are especially noteworthy and extensive where the rocks intruded are massive igneous types. Xenoliths of great size occur on the eastern slope of Seymour Creek Valley south of Mount Seymour, where in one case a prospect shaft has been sunk on the contact metamorphic zone between the batholith and a xenolith. The various stages of assimilation can be observed in various parts of the area, and even where Paleozoic areas are distant occasional fused and distorted fragments are to be found in the diorite. Very good examples of the method of stoping by the intrusion of reticulating veins into fractures in the roof rock may be seen along the eastern side of Howe Sound, where the batholith is in contact with massive Texadan greenstones. Here the separated fragments have extremely sharp fracture-lines and display comparatively little internal recrystallization, while farther away the alteration becomes greater and the outlines lenticular or rounded, until

[1] J. A. Bancroft, *Geol. Surv. Canada, Memoir 23*

FIG. 5.—Aplite dike in Coast Batholith, faulted by [illegible] may be seen passing under the hammer handle. Seym[illegible] R[illegible].

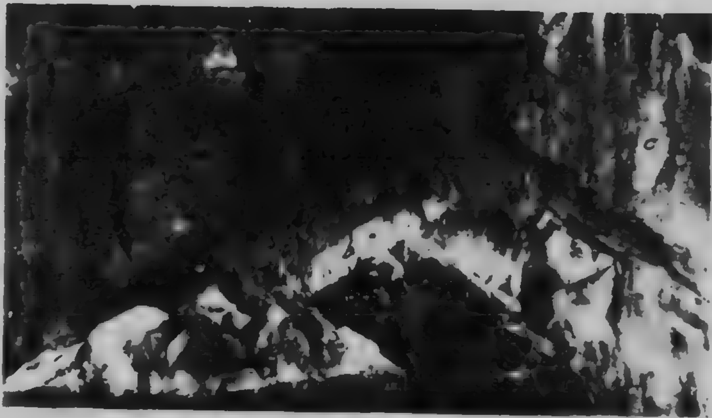


Fig. 6

Fig. 7

Fig. 8

Figs. 6, 7, 8.—Three successive stages of stoping. (1) Penetration of the Texadan [illegible] by dikes [illegible] of the batholith. [illegible] Rifting off of large slabs (a) from the Texadan which [illegible] [illegible] the liquid magma. [illegible] Separated fragments deeper in the magma [illegible] [illegible] and become altered internally, showing a coarser texture [illegible]

finally indefinite smears of hornblende represent what was originally an angular fragment of basalt.

Summary. The intrusion of the batholith may therefore be considered as having taken place in the following stages:

1. Invasion of the overlying rocks by stoping and assimilation of xenoliths.

2. Cooling of the contact-zone, differentiation of the body of the magma, and advancing solidification of the whole mass.

3. Fissuring and deposition in fissures of aplitic end-products.

4. Further movement, resulting in faulting of the batholith with the aplite dikes and the overlying rocks. This was accompanied by hydrothermal action, which produced epidote veins along the fracture-planes of the batholith and replacement deposits of sulphide ores in the Paleozoic rocks near the contact.

5. A slight subsequent fissuring, with formation of small quartz veins.

Differentiation. The following list, based on field relations, indicates the differentiation shells or zones represented in Tables IV, V, and VI, taken in order from the contact-zone or surface of the batholith to the deepest parts of it which are exposed.

1. Contact-zone. Samples generally within 100 feet of contact
   a) Beerbachose. D, E, I, Table IV
   b) Andose. L, Table IV
2. Subcontact-zone. Several hundred feet from contact
   c) Unnamed. A, Table IV
   d) Amadorose. B, C, F, K, Table IV
3. Most acid zone. Still deeper by a few hundred feet
   e) Mariposose. H, Table IV
4. Deep zone. About 6,000 feet below original surface, becoming more basic
   f) Placerose. G, J, Table IV.

The whole indicates a rather rapid increase in acidity from the contact-zone for a short distance downward, followed by a very gradual increase of basicity at greater depths.

It is very likely that a number of intermediate phases exist, and LeRoy mentions types which are much more basic than any studied here.

Andose (*b*) is very near beerbachose, but comes from a locality 40 miles distant from the others.[1]

The presence of orthoclase in phases *b*, *c*, and *d*, of biotite in *b*, *c*, and *f*, and of titanite in *d* should be noted. The plagioclase, which is both

[1] Cf. Daly, *Geol. Surv. Canada, Memoir 38*, p. 532, Slesse diorite.

striated and non-striated, varies from labradorite in the contact-zone (*a*, *b*, and *c*), to andesine near oligoclase in the intermediate zones (*d* and *e*), returning again to andesine near labradorite in the deepest zone (*f*). According to LeRoy the variation is wider, from bytownite to oligoclase. The presence of orthoclase in the contact and subcontact zones (*b*, *c*, and *d*) must be noted.

In general, these rocks differ from those described by Daly from similar batholiths in the Hozameen, Skagit, and Okanagan ranges in being persodic instead of dosodic. Thus the dominant phase of the Similkameen batholith is yellowstonose, which if persodic would be amadorose, while the basic contact-phase is andose instead of beerbachose. The Castle Peak granodiorite is lassenose, as compared with mariposose in the Vancouver batholith. The quartz-diorite of the Chilliwack batholith is tonalose, which if persodic would be placerose.

The processes by which the differentiation of a batholith take place are described by Daly as follows:

1. Gravitational, due to the fact that the basic phenocrysts, such as magnetite, the amphiboles, and the pyroxenes, are the first to crystallize from the melt, and, being heavier than the average of the batholith, sink to its lower horizons, leaving the upper parts relatively acid in composition.

2. Liquation. This is based on the fact that liquids which mix freely at high temperatures separate as the temperature falls, the lighter assuming a position above the heavier by the action of gravity. In this way a cooling magma may split into distinct parts, the more acidic of which will rise above the more basic.

3. The basic contact-shell is accounted for by the fact that the rapidity of cooling at the surface of the batholith leaves no time for the foregoing processes of differentiation, and the contact-phase is therefore like the original magma in composition, probably modified to some extent by assimilation of the invaded rocks.

4. Expression of end-phases. If, when cooling has progressed to such a degree that the growing crystals form a spongy mass throughout the magma with residual liquid in the interstitial space, an orogenic movement takes place under these circumstances, fissures may be formed and the liquor squeezed out of the spongy mass forced into them, resulting in aplitic and pegmatitic end-phases.

These processes are somewhat modified in their operation by the process of stoping, which consists in the shattering of the roof of the batholith owing to heat expansion. The resultant masses sink into

the batholith below. They become fused and assimilated by the molten mass as they descend, and are then subject to practically the same laws of differentiation as the rest. It seems clear to the writer that the depth to which they can sink before becoming assimilated depends upon the size of the fragments, or "xenoliths," and that in the formation of a shattered contact-zone a great deal of "fines" of the size of dust particles or little larger must be produced. This material would be assimilated almost immediately because its small size would cause it to remain in suspension near the contact rather than to sink rapidly, and its relatively large surface would result in speedy fusion due to quicker absorption of heat. Hence it appears that where the invaded rocks are more basic than the original magma it might be expected that the contact-phase would be more basic than it would be in contact with rocks more acid than the magma. The Paleozoic rocks of the Texadan formation are, as a matter of fact, more basic than the basic contact-zone near them, or any known phase of the batholith, but the writer has not had an opportunity of observing the contact-phase where the contact is with rocks more acid than the magma.

As evidence that liquation was operative in the differentiation of the Coast Batholith, the orbicular structure observed in the Capilano Valley may be cited (see page 45), since Daly interprets this structure as an emulsional phase of the magmatic splitting.[1]

The aplitic action is also well shown (page 51), and some of the dikes observed near Caulfields and elsewhere may be due to the expression of the still liquid interior through fissures in the hardened outer part of the batholith.

[1] R. A. Daly, *Geol. Surv. Canada, Memoir 38*, p. 770.

CHAPTER VII

ECONOMIC ASPECTS

CONTACT METAMORPHISM

As already stated, the contact-zones of the Paleozoic roof pendants with the batholith are of great economic interest, since it is here that metalliferous replacement deposits occur. None of these is at present producing ore in the areas examined by the writer, but the Britannia mine, which lies a short distance to the north, as well as many others, including those of Texada Island, the Portland Canal mining area, and the Whitehorse copper range, are of similar origin, and such data as have been collected in the area here described may assist in solving problems common to many of the Coast Batholith ore deposits.

The deposition of metallic minerals took place in both the Texada and the Britannia formations. Of the Texadan areas examined, those which consist exclusively of igneous or meta-igneous rocks, including the Black Mountain, Mount Strahan, Caulfields, and Seymour Ridge areas, show little or nothing of metalliferous deposits. The only exception is the showing on which, as already stated, a prospect shaft has been opened on the east slope of Seymour Valley. In this case the metallic content, which consisted of possibly auriferous pyrite, was carried in small reticulating quartz veins, which appeared to be subsequent to the epidote-producing hydrothermal injection, and were therefore of a type quite different from the replacement deposits which are most characteristic of the region. The quartz veins contain brecciated fragments both of the greenstone xenolith, which forms the walls, and of the epidote veins which penetrate it. The whole occurrence is on a small scale, and probably of no economic value, but interesting as indicating the fact of vein formation at a time after the latest batholithic action elsewhere seen. The wall rock is found microscopically to consist of kaolin, quartz, and sericite, with smaller grains of epidote and titaniferous magnetite, partly altered to haematite and leucoxene.

The Lynn Creek Texadan area, in which alone replacement deposits of any promise occur, is largely composed of meta-sedimentaries. They include "marble, dolomite, quartzite, garnetite, epidote schist, and allied metamorphic minerals. Of these, crystalline limestone has the most important effect on metasomatic action, since in most of the observed

cases the ore deposits are located along limestone lenses. They occur along fracture-zones parallel to the limestone lenses, and also along faults which have in most cases an east-and-west trend, transverse to the bedding. The faults and fracture-zones formed avenues for the circulation of hydrothermal waters. The faults are of those previously described as having occurred after the aplitic phases of the batholith had solidified and in which the epidote veins of the batholith were deposited. Mineralization therefore took place during or after this movement. The following facts are also of importance:

1. The principal deposits are of tabular form and are those parallel to the strike of the limestones, while those along fault-planes are of minor importance, and extend for short distances from the intersection of the fault with the limestone (125 feet was the maximum distance observed).

2. Highly altered fragments of the shattered rock are found in the ore.

3. At the intersection of the fault-planes the bedded deposits widen and crushed rock is more completely replaced by ore.[1]

These data indicate that the ore was deposited along planes of fracture, that replacement of the crushed rock and also of the wall rock took place, and that the hydrothermal waters gained access to the fracture-planes along the transverse faults, which extend into the batholith. It is also apparent that the presence of the limestone determined the deposition of the ore.

At the time when the writer visited the Lynn Creek area the only properties where any work was being done, and where in consequence information could be satisfactorily obtained, were those belonging to the Lynn Valley Zinc Mines (Ltd.). In this case on the Kemptville Extension Claim there are two bedded veins of steep dip. Each of the two lies along a stratum of limestone, in the manner indicated in the annexed plan and (hypothetical) structure section. The west vein is only a few feet from the contact of the batholith, which is here represented by a strongly hornblendic granular quartz-diorite (beerbachose, see Table IV, page 47, sample I). The quartz exhibits strain-shadows, and the feldspars are of zonal structure, for the most part andesine, but with zones of labradorite. An unusual accessory is pyrite, in addition to the commonly occurring magnetite and apatite. The alteration products are kaolin and sericite. Penetrating the diorite, and extending into

[1] The author is under much obligation to Mr. Emmons, the engineer in charge at the Kemptville Extension Claim, for information and courtesy in facilitating the examination of the property.

the Texadan schist, are the usual veins of epidote and quartz, which occupy fault-planes. These veins extend as far as the limestone, a distance of about thirty feet, and then appear to spread laterally along it, forming a tabular vein parallel to the limestone bed, which contains

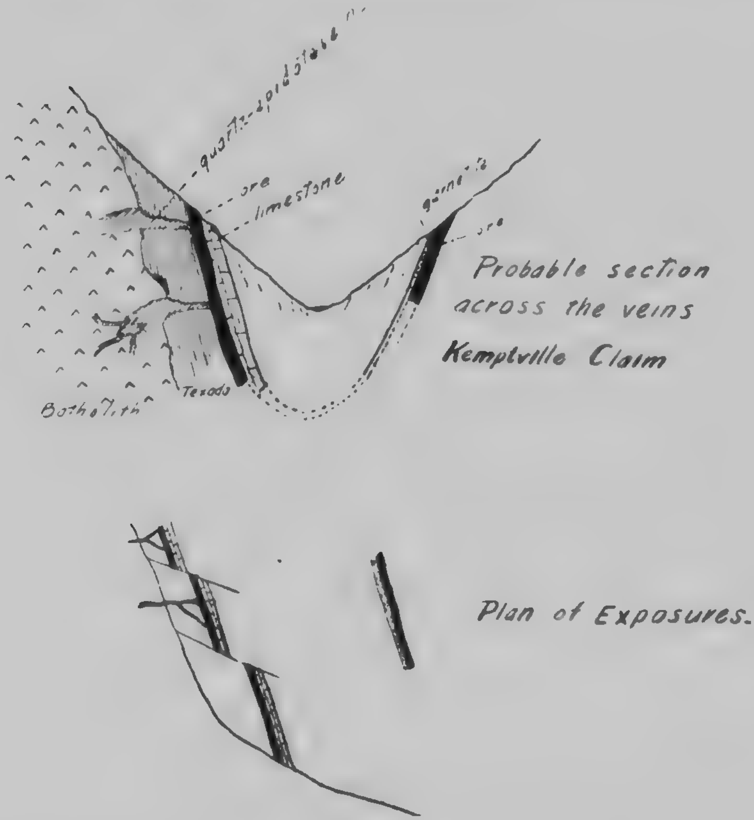


FIG. 9

a large amount of sphalerite, chalcopyrite, pyrite, and pyrrhotite in a gangue of epidote and quartz. A considerable amount of iron pyrites in cubes has been developed also in the country rock on the side of the vein opposite to the limestone, and definite walls are hard to find. Higher up the hill a deposit apparently on the strike of the western ore body is said to display a banded alternation of galena and zinc blende.

In this case the process of deposition would appear to have been ordinary fissure-filling. On the I[illegible]otville Extension, on the other hand, there are no very definite wal[illegible] the ore fades gradually into the country rock. There is no doubt [illegible]e occurrence of metasomatic action there, and the deposition in fissures farther north may have been due to this action, which might add to the circulating waters in the fissure reagents which would induce precipitation, as in the fault-planes adjacent to the limestone. Besides those mentioned, other metallic minerals on this and adjoining properties are molybdenite and magnetite. Some small bodies of chalcopyrite and pyrite occur along the actual contact between the Texadan schist and the diorite, but most are within the Texadan along the various limestone lenses.

Among the minerals developed in the crystalline limestone are garnet, spinel, plagioclase, pyrite, magnetite, sericite, and epidote. The garnet is a lime-iron variety. These minerals are all characteristic of metasomatic processes at a considerable depth.

A section of the ore from the Swayne Copper group was found to consist of pyrite, chalcopyrite, and magnetite, through which are distributed rounded grains of augite, which are in some places massed together, and their interstices occupied by garnet. The augite and garnet are evidently older than the sulphides, which are interstitial where they and the silicates are intermingled. The ore body is said to be a mineralized zone in diabase.[1] Much epidote vein-rock is also present. It is possible that the augite in the ore is part of the original diabase, while the soda and lime of the feldspar have been replaced by the metallic sulphides, and the residual Al_2O_3 and SiO_2 of the feldspar have contributed to the formation of the garnet, together with small amounts of lime and iron. This would agree with the relative ages of the minerals.

On the western side of Lynn Ridge, near the contact, there is a limestone of granular texture in which are rounded grains of brucite which have characteristic streaky extinction, and smaller grains of pyrite, magnetite, spinel, and plagioclase. In other cases epidote, colorless pyroxene, and secondary quartz are present, as well as brucite. These rocks seem to correspond to the predazzite and pencatite types described by Lenecek.[2] The type in which grains of iron oxide and sulphide are present would be pencatite, though perhaps not closely representative of the original type, in which they seem to be very finely disseminated.

[1] *Report of the Minister of Mines of British Columbia*, 1908.

[2] Ottokar Lenecek, Tschermak's *Mineralogische und petrographische Mitteilungen*, XII (1891), 429.

The other type, in which colorless pyroxene and quartz grains appear, corresponds fairly well with predazzite, though epidote is not mentioned in the original type.

The facts as to ore-genesis in this area therefore appear to be as follows:

1. The ores were formed by the action of hydrothermal waters, which were the last, or near the last, stage of the igneous action.

2. They were formed at a considerable depth below the surface, where the pressure was high.

3. The chemical processes which took place involved the removal of CaO from the invaded rocks, and the deposition of silicates, especially of lime and iron, sulphides of zinc, lead, iron, copper, and molybdenum and iron oxide (magnetite) in their stead. The importance of the $CaCO_3$ as a reagent is apparent from the fact that where it is absent there is in most cases no ore body, but only a deposit of epidote, both within the batholith and in intruded rocks. Occasional grains of magnetite and a slight amount of quartz also are discernible in these veins. The transportation of large quantities of metallic ions to the points of deposition must have involved considerable time. As the movement was in general ascending, it may be argued that diffusion was assisted by a tendency to move from greater to less pressure, independent of the movement of the liquid as a whole. A possible explanation also is that electrolytic conditions were established owing to the more rapid cooling of the rock in the zones of contact than deeper within the batholith where the hydrothermal waters originated.

The deposits of this area may be classified either as contact metamorphic deposits or, where tabular and located along faults or shear-zones, as veins of the deeper zone.

In the Britannia slates of Castle Towers Mountain samples of copper ore were obtained by the late Mr. H. H. Korten, and the deposit there, while not extensive, is probably of similar type to that of the Britannia mineral zone in which auriferous copper and iron sulphides occur as an impregnation in quartz-sericite schist.

[illegible]

CHAPTER VIII

EOCENE

THE PUGET SERIES

After the intrusion of the Coast Batholiths, a long period ensued whose only record is erosional. This interval, in the region here described, occupied the whole of the Comanchean and Cretaceous periods; and erosion meantime progressed far enough to unroof the batholiths, since the Eocene deposits of the Puget series are found lying on an eroded surface of diorite. The contact exposure is in the lower canyon of the Capilano, immediately north of the Keith Road bridge. The diorite surface on which the basal member of the Eocene rests has a southerly dip of about 12°. The basal member of the Puget series is a coarse conglomerate which consists of rounded bowlders from the batholith and Paleozoic rocks, imbedded in a matrix of feldspathic sand in which flakes of a ferromagnesian mineral, probably mica, appear. The vertical thickness of the conglomerate has been found by a boring in the Capilano Delta to exceed 250 feet.[1] The stones of the conglomerate do not, as a rule, exceed a foot in diameter, and are mostly smaller.

The first beds visible above the basal conglomerate are the thick-bedded somewhat ferruginous yellow feldspathic sandstones of Prospect Point, and similar beds are exposed at various points along the south side of Burrard Inlet, especially near the Canadian Pacific Railway station, on a point just west of the second narrows and in the northern face of North Mountain, between Hastings and Port Moody. In the interval between the exposures at the Canadian Pacific Railway wharf and those near the second narrows a depression in the rock surface exists, underlying the low neck of land that separates the head of False Creek from the Burrard Inlet. This was determined by a boring made at the packing-house of P. Burns & Company, where 480 feet of drift were penetrated before the rock was struck. Unfortunately no accurate account of the strata penetrated below this depth was kept. The rocks are stated by Mr. Walter Ray, manager for the company, to have been sandstone and shale, among the latter occurring two or three very soft beds which were difficult to drill and two or three seams of coal from 1½ to 4 inches in thickness. An exceptionally hard bed, possibly an

[1] Professor A. C. Lawson, private communication.

indurated feldspathic sandstone, was encountered at 1,100 feet, and the drilling was discontinued at 1,448 feet, as no water had been encountered and the probability of obtaining a flow seemed to be remote. The bottom of the Eocene strata was not reached. To the east of the second narrows the Eocene strata assume more markedly the nature of an escarpment bordering the south side of the inlet, and the resulting ridge, known locally as North Mountain, attains a height of 1,335 feet to the south of Barnet. It is quite abrupt on the north face, sloping gradually on the south side to the trough of Brunette Creek and Burnaby Lake. Here a small outcrop occurs at an altitude of about 50 feet. A gap passes through the ridge opposite the mouth of the North Arm and is no doubt a trough valley cut by the glacier issuing from that fiord, while Burrard Inlet was occupied by a piedmont glacier. The trough of Burrard Inlet, throughout its length, has obviously the structure produced by stream erosion on a sloping contact. The height of the escarpment on the south side, together with the dip, suggests that the Eocene strata originally extended a considerable distance farther north, but no outliers have been found on the north side of the inlet so far as the writer is aware. The contact crosses to the north side of the inlet about two miles northwest of Port Moody. The basal conglomerate reaches an elevation of 140 feet at the lower Capilano Canyon, and at Wolfsohn Bay and northwestward from it sandstones provisionally assigned to this formation extend far inland, presumably to some considerable elevation.[1] In the Cascades they have been found at altitudes of from 800 to 5,000 feet.[2]

A section of 466 feet, lying above the conglomerate, has been recorded by Richardson. It contains a few beds of dark-red shale, and was obtained from an exploratory drill-hole on the south side of the inlet near the entrance.[3]

Following the west side of the Stanley Park Peninsula southward the sandstones are found to be interstratified with shale and to contain here and there small streaks of lignite. The dip averages from 10° to 15° south.

The Puget beds are again exposed on the south side of English Bay, at Kitsilano, where they dip south by east 10°. They are also well exposed in the Great Northern Railway cutting through Grandview Heights which crosses Commercial Road to the east of the head of False

[1] O. E. LeRoy, *op. cit.*, p. 24.

[2] Sir J. W. Dawson, "On Collections of Tertiary Plants from the Vicinity of the City of Vancouver, B.C.," *Royal Soc. Can. Trans. and Proc.*, 2d Ser., Vol. I, sec. IV, pp. 1[illegible]-31 (1895).

[3] *Geol. Surv. Canada, Report of Progress*, 1876-77, p. 189.

Creek. Here and at Stanley Park there is evidence of gentle anticlinal folds which have a north-and-south direction, or transverse to the general line of strike. This folding may have taken place as late as the Pleistocene, since the glacial beds above have undergone some faulting, and the rise of the anticline at Grandview may then account for the interrupted channel between False Creek and Burnaby Lake. The most southerly exposure of the Puget formation[1] which was seen is in the bed of Brunette Creek near New Westminster, but there is little doubt that the formation underlies the whole of the lowland to the international boundary and beyond.

The shales of the Puget series afford fairly perfect leaf impressions. These have been studied by Sir J. W. Dawson,[2] who determined the following species from collections made by A. C. Lawson, G. M. Dawson, James Macoun, G. F. Monkton, and C. Hill-Tout, at Stanley Park, Hastings town site, and elsewhere in the vicinity of Vancouver.

Ferns, etc.:
- *Lastrea fischeri*
- *Neuropteris civica*
- *Lygodium neuropteroides*
- *Asplenites* sp.
- *Glyptostrobus europeus*

Palms:
- *Sabal campbelli*
- *Manicaria* sp.

Cyperiaceae (sedges):
- *Cyperites paucinervis*
- *Carex vancouverensis*
- *Carex burrardiana*

Dicotyledons:
- *Populus balsaminoides*
- *Populus rotundifolia*
- *Salix varians*
- *Salix integra*
- *Dyophyllum stanleyanum*
- *Quercus dentoni*
- *Platanus* sp.
- *Juglans denticulata*
- *Aesculophyllum* (sp. nov.)
- *Ficus shastensis*
- *Ficus occidentalis*
- *Planera crenata*
- *Sequoia heeri*

And others.

[1] Noted by Bauerman, *Geol. Surv. Canada*, 1882–83–84, p. 10 B.

[2] Sir J. W. Dawson, *op. cit.*

This flora, including as it does ferns, palms, sedges, cotton-woods, willows, oaks, figs, and redwoods, indicates a climate probably considerably warmer than the present, but somewhat colder than that represented by the Chico (Nanaimo group), which underlies the Puget in the state of Washington. A present-day climate corresponding to it is that of central California. The flora as a whole occupies a distinctly intermediate position between those of the Chico (Upper Cretaceous) and the Similkameen beds of the interior, which are Oligocene, and is similar in facies to the Fort Union or Upper Laramie flora.

Allowing for an average southerly dip of 10° from the Keith Road bridge to the south side of English Bay, a distance of 5 miles, the stratigraphic thickness of the deposits would be about 4,500 feet, and, as the dip seems to be well maintained for that distance, it is probable that a further thickness is added to the south of the accessible beds. The total thickness in the state of Washington is estimated at 10,000 feet.

The materials which compose the formation in the Vancouver area are manifestly near their source, since the feldspathic and siliceous constituents have not been well separated by transportation. They are, in fact, the materials of the adjoining range, as shown by the granites, schists, and quartzites of the conglomerate. The conditions seem to have been those of piedmont deposition in shallow water, and the whole formation is indeed regarded as estuarine by J. W. Dawson. Some periods of subaerial deposition are indicated by stumps *in situ* in the coal beds of the Puget Sound region.[1] Such animal fossils as exist indicate fresh or brackish water. The formation as a whole extends from Burrard Inlet nearly to the Columbia River along the west coast geosyncline. Its equivalents in time elsewhere are given by Dawson as the Upper Laramie, or Fort Union, the Atane Kerdluk of Greenland, and the lignite series of the McKenzie River.[2] It may also be equivalent to the lower Clarno of the John Day basin.[3] The horizon of all these is Paleocene or Lower Eocene. Farther south the upper part of the series is believed to be Miocene. The name Huntingdon formation has been given by Daly to what appears to be part of this series exposed on the south side of the Fraser Valley near Sumas.

[1] J. H. Bretz, "Glaciation of the Puget Sound Region," *Washington Geol. Surv.*, [illegible] p. 13.

[2] Sir J. W. Dawson, *op. cit.*

[3] F. H. Knowlton, *U.S. Geol. Surv., Bull.* [illegible]

Coal.—**No coal seams of commercial importance have yet been** discovered in this formation to the north of the international boundary.

Clays.—At Clayburn, some 50 miles from Vancouver by rail, clays or shales of this formation are being used in the manufacture of fire-brick and also for ordinary pressed brick. The fire-clays underlie and overlie a thin seam of lignite whose acid secretions have acted to dissolve and leach out the iron, magnesium, calcium, and alkaline compounds. The former of these metals is ordinarily among the most persistent residuals,

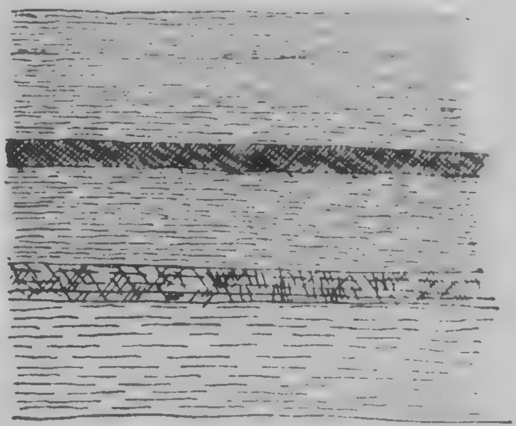


FIG. 11.—Section of refractory clay beds at Clayburn, B.C.

and the ordinary clays of the neighborhood contain about 9 per cent Fe_2O_3 and from 1 per cent to 6 per cent of CaO. The following analyses of two of these clays are taken from the ***Report of the Minister of Mines for British Columbia*** for 1908. The fusibility-points, as stated, would place No. 3 in the class of "Flint Clays," adopted by Bleininger, and No. 1 in "No. 2—Plastic Fire-Clays." The closeness of their approach to the molecular composition of kaolin, which is recognized as the standard of purity, is indicated in Tables VII-X. The No. 3 clay is rather siliceous, but the amount of impurity (metallic oxides) is small, while No. 1 has very little free silica but a higher metallic content.

The action of the acids from the coal seam, as indicated by the annexed section, has been effective above as well as below the seam, though more strongly in the downward direction. If, as is to be supposed, the action took place below the ground-water level, where the

movement of the water would be very slow and in general horizontal, diffusion would account for the action in the upper stratum of clay. The concentration of the iron oxide in the clay stratum intermediate

TABLE VII

"No. 3" Clay, Seger Cone 33

	Percentage Comp.	Molecular Weight	Molecular Ratio	Ratio to $Al_2O_3 = 1$	
SiO_2	58.5	÷ 60	= 0.975	3.3	
Al_2O_3	30.55	÷ 102	= .297	1	
Fe_2O_3	0.65	÷ 160	= .004	0.013	
CaO	0.0	÷ 56	= [illegible]		0.053
MgO	0.5	÷ 40	= .012	0.04	
Alkalies taken as K_2O	0.0				
Water	9.5	÷ 18	= 0.53	17	

TABLE VIII

No. 1 Clay, Seger Cone 31

	Percentage Comp.	Molecular Weight	Molecular Ratio	Ratio to $Al_2O_3 = 1$	
SiO_2	60.55	÷ 60	= 1.009	2.8	
Al_2O_3	35.25	÷ 102	= 0.354	1.0	
Fe_2O_3	2.75	÷ 160	= .017	0.04	
CaO	0.25	÷ 56	= .004	0.01	0.1
MgO	Tr	÷ 40	= 0		
Alkalies taken as K_2O	1.88	÷ 94	= 0.02	0.05	

TABLE IX

Comparative Table of Molecular Ratios

	SiO_2	Al_2O_3	Metallic Oxide	Water
Kaolin	2	1	0	–
No. 1 clay	2.8	1	0.1	
No. 3 clay	3.3	1	0.053	0.17

TABLE X

Approximate Mineralogical Composition

Clay	Kaolin	Free silica	Impurities	Total
No. 1	89.18	6.62	4.48	100.08
No. 3	77.20	24.26	1.15	97.70

between clays (1) and (3) constitutes a problem for whose solution no definite data are available. A number of non-refractory beds are also used at Clayburn in the manufacture of tile and pressed brick of several colors. Fire-clays exist also in the Huntingdon formation at Sumas Mountain.

Petroleum.—Some borings have been undertaken, especially at Pitt Meadows, with the object of finding petroleum, but these have so far proved unsuccessful.

CHAPTER IX

POST-EOCENE ERUPTIVES (BLACK TUSK BASALTS)

The effusive eruptives at Stanley Park and on Fairview Heights have been described by LeRoy. At Stanley Park a dike extends from Siwash Rock to Prospect Point, where it forms the conspicuous columnar wall seen when approaching the harbor mouth from the westward. The dike at this point has a thickness of 50 feet and rises 200 feet above the sea. It consists of a "greenish-gray non-porphyritic quartz-trachyte with irregular vesicular cavities partially filled with quartz-crystals showing pyramidal terminations." The vesicular structure "which is present in the upper part of the mass" disappears in the lower portions "and the rock becomes more compact." The presence of vesicular cavities in the upper part undoubtedly indicates that this portion of the eruptive was very near the upper surface of the liquid mass and that this surface was subaërial. After examining with some care excavations that have been made since LeRoy's report was written, it seems not improbable that the upper parts of the eruptive extended horizontally as a surface flow, whose presence beneath the drift and humus may explain the level-topped hill that occupies several acres in this part of the park. If these rocks have been exposed to erosion since Miocene times, which is possible, it is to be supposed that a considerable part of the original superficial extent has been removed, and that only the part which lies immediately adjacent to the center of extrusion remains.

A smaller vertical dike some six or eight feet in thickness runs in an east-west direction a short distance south of Siwash Rock. It has a moderately well-developed transverse columnar structure and is described by LeRoy as decomposed andesite. The dikes have produced a somewhat porcelaneous appearance and consistency in the feldspathic sandstone of the Puget series for a distance of two or three feet from the eruptive contact.

An effusive mass also forms the upper part of the ridge of Fairview Heights. It "consists of phenocrysts of plagioclase feldspar and augite in a matrix of the two. Magnetite is present in large amount as inclusions in the augite."[1]

[1] LeRoy, *op. cit.*, p. 25.

[illegible] The [illegible] from Mount [illegible] [illegible]

[illegible] The [illegible] [illegible]

LeRoy also describes the effusive which occurs to the north of Watt's Point on Howe Sound as correlative with the two already mentioned.[1] It has two phases—a superficial one of black pitchstone and a lower gray cryptocrystalline phase. Both are vesicular, and the black selvage has columnar jointing. Microscopically both phases consist of "stout and slender phenocrysts of augite, and a few tabular individuals of medium labradorite, in a matrix of laths and acicular forms of plagioclase and augite, and gray or brown isotropic glass. There is considerable magnetite in minute grains." Flow structure is especially noticeable in the black upper phase. The rock is therefore a basalt rather than an andesite. Its black and gray phases correspond very well with similar phases in the much thicker flows in the Black Tusk and Table mountains to the north, which are also basaltic, but its lithology and position in the valley of Howe Sound will be shown later to favor the hypothesis that it is of much later age, unless faulting, rather than erosion, can be shown to have played the greater part in the excavation of the valley. While it may be admitted that there are other reasons for entertaining the idea of faulting, the petrology of the rocks agrees much more nearly with that of the later Garibaldean series.

In the region which extends northward from Mount Garibaldi there are very similar rocks which form the summit of Black Tusk and Table mountains, and it is probable that Columnar Mountain, to the south of Mount Garibaldi, also consists of lavas of the same period. Black Tusk Mountain is an isolated peak which rises about 2,100 feet from the floor of the terrace north of Lake Garibaldi and attains a total height of 7,350 feet (aneroid). The first 700 feet above the base consist of tilted beds of the Texadan and Britannia formations, on whose truncated upper surface lies a thickness of about 600 feet of gray porphyrite having a crypto-crystalline groundmass. It is in part columnar in structure and in parts divided by parallel joints into a mass of plates about one inch in thickness which display various radial and booklike arrangements, but are in general vertical. On top of this is a pinnacle of black basalt of vitreous luster about 800 feet in height. It has columnar structure, but the columns are in general smaller than those of the gray rock beneath. Near the contact of the two types there is a certain amount of red lava which weathers to an earthy product. This, as far as could be readily determined, appears to have been of vesicular texture and may therefore represent the surface of the gray lavas beneath. The columns in the Black Tusk pinnacle are irregularly or radially arranged and are

[1] *Ibid.*, p. 26.

seen to fine advantage in the immense cliff which on the eastern side overhangs a cirque leading to the northward. The lower lava contains inclusions of the older (Paleozoic) porphyrite, and in one place a bowlder of Britannia conglomerate traversed by a small apophysis of the Jurassic batholith was found imbedded in the lava. The pinnacle has been thought to be a volcanic neck, but investigation leads to the conclusion that it is a remnant of an upper vitreous flow which overlies the gray felsitic lava. It probably formed a nunatak during the existence of the ice sheet, as indicated by its jagged outline and the presence of much loose material on its summit. The surface of the lower part of the flow, which extends westward horizontally for some distance from the base of the pinnacle, at an altitude of about 6,500 feet displays evidence of ice action. The Tusk itself is surrounded on its west and south sides by a talus of broken columns, and on its north and east sides forms the wall of deep snow-filled cirques.

On the southwest side of Garibaldi Lake the same rocks are exposed over an area about three miles from north to south by a mile and a half from east to west. The gray underlying portion forms part of the platform on which the later volcanic cone of Red Mountain stands, and the post-Eocene lavas are somewhat difficult to distinguish macroscopically from the gray lavas of the Garibaldi eruptive series. The post-Eocene lavas have, however, in general, a more weathered appearance and a distinct system of joints even where not markedly columnar, and are separated by a very considerable erosion interval from the Garibaldi Pleistocene volcanics. The relations of the two sets of lavas are best understood by reference to Fig. 14, p. 71. The greater part of the "post-Eocene" area consists of the lower gray lavas, which in some parts display remarkably perfect columnar structure. The columns are as frequently horizontal as vertical, and no great continuity in their arrangement was anywhere observed. At the southern end of the area a flat-topped remnant of the upper pitchstones (known as "The Table") lies upon the gray lavas. It is also columnar in structure, the diameter of the columns being less than those of the gray lavas underlying, and the two types here correspond with those in the Black Tusk Ridge. The basaltic rocks of Columnar Mountain lie in a continuation of the line from Black Tusk through the Table Mountain area, and the three areas apparently represent an originally continuous belt extending due north and south for about twelve or thirteen miles, and not over two miles in width. The granite peaks of Castle Towers and Sentinel mountains rise immediately to the east to a height somewhat greater than that of

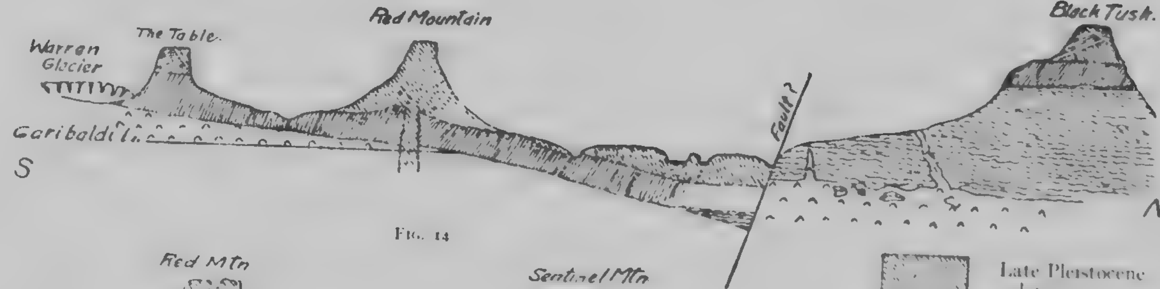


Fig. 14

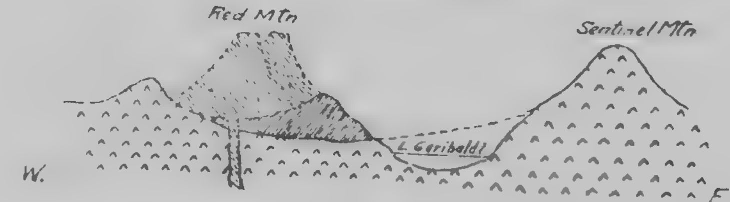
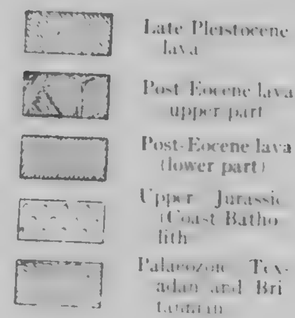


Fig. 15

Cross-section to show Miocene? Valley filled with lava, and subsequent erosion and vulcanism.



FIGS. 14, 15.—Geological relations of post-Eocene eruptives

the lavas, and are divided from them by valleys of much later origin. The whole suggests that the basalts flowed along a valley excavated in the older Paleozoic and Jurassic rocks, which at that time must have had a topographic relief of more than 2,000 feet, since the summit of Castle Towers Mountain is at 8,000 feet elevation, while the base of the lavas in Black Tusk Ridge has an altitude of about 6,000 feet (Fig. 15). The difference in elevation between the base of the lavas on the east side of Table Mountain and the summit of Sentinel Peak a mile farther east, is at least 1,500 feet. Their summits are about equal in height. The lava here has therefore a depth of about 1,500 feet. Its top and that of Sentinel Peak may represent a level of erosion subsequent to the vulcanism, or the valley may have been completely filled by the lava.

The valley in which the lavas congealed was probably above sea-level at the time, though not more than a few hundred feet at the point in question, as it appears to have been somewhat mature and therefore of gentle gradient. This indicates a subsequent rise of from 4,000 to 5,000 feet for the region. If the basalts on the north side of Watt's Point, which are at sea-level, belong to the same flow, it appears that that part of the valley is now at about the same level as when the lavas were extruded, and faulting must be relied upon to explain the relative levels of the two lavas near the head of Howe Sound and at Columnar Mountain. The difference in elevation between the base of the Black Tusk area and that of the Table Mountain area undoubtedly indicates a fault of east-and-west trend along the north shore of Lake Garibaldi, the escarpment of which extends from Castle Towers Mountain to the Cheakamous Valley along the line of Stony Creek.

PETROLOGY AND CORRELATION OF THE LAVAS

The rocks of this series have been previously described as andesites,[1] and not as basalts, presumably following a classification which distinguishes basalt from andesite by the presence of olivine in the first-mentioned. In the present paper igneous rocks are classified on the basis of the feldspars they contain, and, following this method, the rocks at present under discussion are basalts, or at most andesite-basalts, since in some cases the zonal feldspars are in part andesine, though for the most part labradorite. Table IX indicates sufficiently the similarities and dissimilarities between the effusives which have been assigned to this series at their various occurrences within the region examined.

[1] O. E. LeRoy, *Geol. Surv. Canada, Publication 996*, pp. 25, 26.

It will be seen that the Watt's Point basalt differs from the others in the absence of magnetite inclusions in the augite, in the emphasis on the amount of magnetite in the groundmass, and in the absence of hypersthene. In all of these respects it agrees with the lavas of the Garibaldi series, and it has therefore been assigned to them. In the absence of a definite determination of the feldspar at Fairview Heights by LeRoy, the presence of augites filled with magnetite inclusions seems to imply that this effusive is to be correlated with those of the Black Tusk and Table Mountain areas. The last two are therefore probably post-Eocene, since the Fairview effusive cuts the Puget formation. They are nowhere overlaid by rocks of earlier than Pleistocene age, and their position between these limits must be a matter of probability at best. Among the factors that bear upon the question of their date are the following:

1. The extent of the subsequent erosion. The upper surface of the lava, which must have been at first considerably below the higher elements of the surrounding topography, is now very nearly or quite accordant with the general summit level of the range, while its base is in observed cases 5,000 feet above the bottom of the deeper valleys adjoining. In the greater part of the area it is evident that several hundred feet of the lava itself has been removed. This would not be conclusive evidence of age greater than early Pleistocene, i.e., post-Methow, and before full Entiat maturity, if we make the summit level of the range equivalent to the Methow of Smith and Willis.

2. The chloritization of ferromagnesian constituents, notably augite, which is in many cases complete, and the development of a small amount of kaolin within the feldspar require a considerable amount of time. There are also certain jointing effects which appear to be due to subsequent earth movement rather than to cooling. These facts, and the amount of erosion suffered, place the lava as definitely older than the Garibaldean lava.

3. The immense quantities of similar basalts erupted in closely adjoining regions during the early and middle Miocene afford a strong presumption that those in the region under consideration are of the same age, and it seems therefore possible that these are to be correlated with the Taneum andesites or Yakima basalts of Washington and with the Miocene basalts of the interior plateau of British Columbia. With the first-mentioned they have a lithological agreement. The rocks of this series from the Mount Garibaldi region are hypersthene basalts, or, under the old classification, hypersthene andesites. In general they may be said to consist of a groundmass of plagioclase microliths and

magnetite grains with more or less intersertal brown glass, in which are sparingly scattered laths of labradorite and hypersthene, larger zonal plagioclases, which vary from andesine to labradorite or bytownite and have generally inclusions of glass often horizontally arranged, and pseudomorphic masses of augite containing large amounts of included magnetite and hematite, which has often the outlines characteristic of hornblende and has been produced by fusion of the hornblende crystals which have recrystallized as augite with a separation of iron oxide. The upper flows are more vitreous types of essentially the same magma, containing a larger amount of glass and more tabular plagioclases in the groundmass.

A Miocene lava which closely resembles that of the Black Tusk series is the "Taneum andesite[1] of G. O. Smith, a 'hypersthene andesite' with phenocrysts subordinate in amount to the groundmass. The plagioclase phenocrysts are zonal and chiefly labradorite. The pyroxene is represented usually by replacement material, which appears to be iddingsite. These pseudomorphs generally show the characteristic outline of hypersthene, which was without doubt the principal ferromagnesian constituent. The andesite generally is considerably altered. Accessory constituents are magnetite and apatite. The groundmass is hypocrystalline, showing laths and prisms of plagioclase and replaced pyroxene."

At Clealum Point on the Yakima River, Washington, a rock closely associated with the Taneum occurs which contains brown hornblende in addition to plagioclase and hypersthene, while the groundmass contains plagioclase laths and grains of quartz and orthoclase. The Taneum andesite and Clealum Point rock are placed by G. O. Smith in the lower Miocene. The more acidic phases present are somewhat comparable to the quartz-trachyte of Prospect Point, Stanley Park.

On the other hand, hypersthene andesite was erupted in the Tieton basin of central Washington[2] in Pleistocene times after the uplift of the Methow, and has since been eroded by the Tieton River. The third point, that of lithological resemblance, might therefore be decided in favor of either Miocene or Pleistocene age.

Summing up the evidence, there is evident physiographic difficulty in making this lava older than the summit level peneplain (see chap. xi, p. 96), though the possibility of such an age is discussed in the place referred to. On the other hand, the weathering and jointing of the

[1] *U.S. Geol. Surv., Mount Stuart Folio* (106), p. 7

[2] G. O. Smith and Bailey Willis, *U.S. Geol. Surv., Professional Paper 19*, p. 18.

rock prove only that it is somewhat older than the Mount Garibaldi and Red Mountain lavas, from which it is separated by an erosion interval

The evidence as a whole seems to favor the theory that these lavas were extruded after the elevation of the summit level had begun and while the subsequent Entiat erosion was still in progress, but had not as yet reached the full maturity to which it attained before the "Twisp" uplift.

The peculiar aggregations of magnetite with a yellow mineral intersertally placed, which have as a whole the outlines of hornblende crystals, are probably to be accounted for by a process of resorption very similar to, if not identical with, that described by Rosenbusch,[1] in which basaltic hornblende, when the magma will no longer support it, becomes replaced by magnetite and augite. That these are due to the presence of hornblende in the magma originally is also rendered more probable by the occurrence of basaltic hornblendes in some bowlders from the Capilano Valley drift which may be ascribed to this formation. In these, brown basaltic hornblendes are surrounded by reaction rims of iron oxide, or, in many cases, partially replaced by augite in grains arranged in rows around their borders and filling out pseudomorphously the original outline of the eroded hornblende. A further noticeable point in favor of resorption, as opposed to secondary alteration, consists in the fact that the groundmass around the magnetite-augite-chlorite pseudomorphs displays an arrangement of its microliths in flow lines, while no such phenomenon is noticeable around the borders of the hypersthene and labradorite, which are, moreover, themselves almost entirely unaffected by secondary alteration. The outlines of the pseudomorphs also are rounded as if by partial fusion.

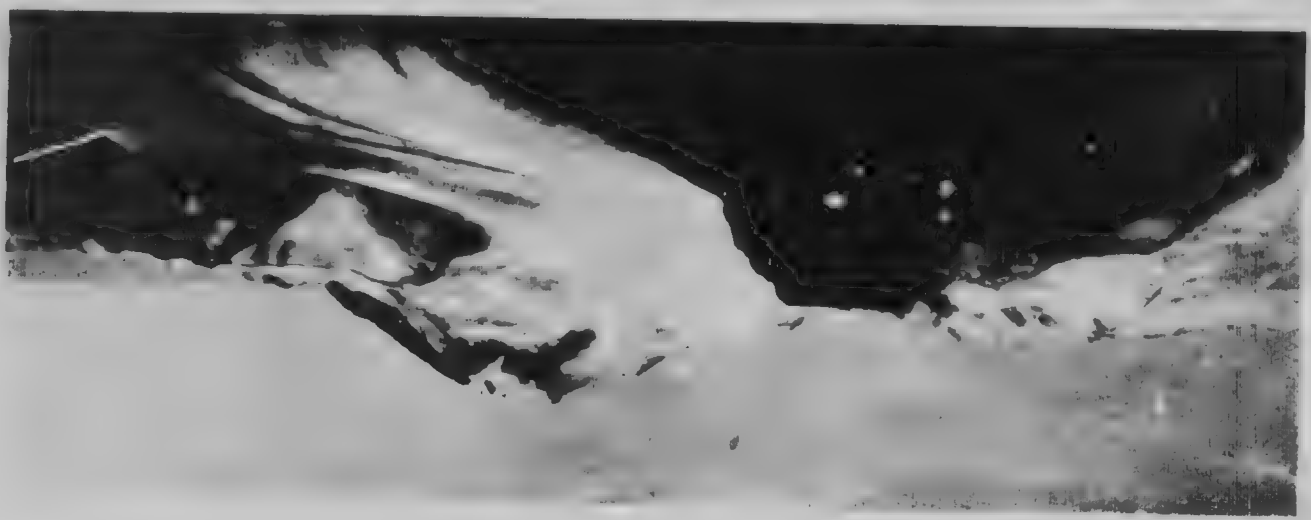
The writer has not microscopically studied the rock described by LeRoy from Fairview Heights, and the suggestion that it is probably the lithological equivalent of the Black Tusk basalts is therefore made somewhat tentatively. Moreover, there is no ground other than lithological on which these effusives can be certainly correlated with Black Tusk basalts. Their age is post-Eocene and pre-Admiralty.

Economic.—The eruptive rock of Stanley Park has been used to some extent in the park itself as road metal, but it is probable that less vesicular types of rock will be found much superior for that purpose. A quarry at Fairview Heights has furnished a considerable quantity of the eruptive there, which has been found somewhat too easily crushed for road metal, but used to a considerable extent as railway ballast.

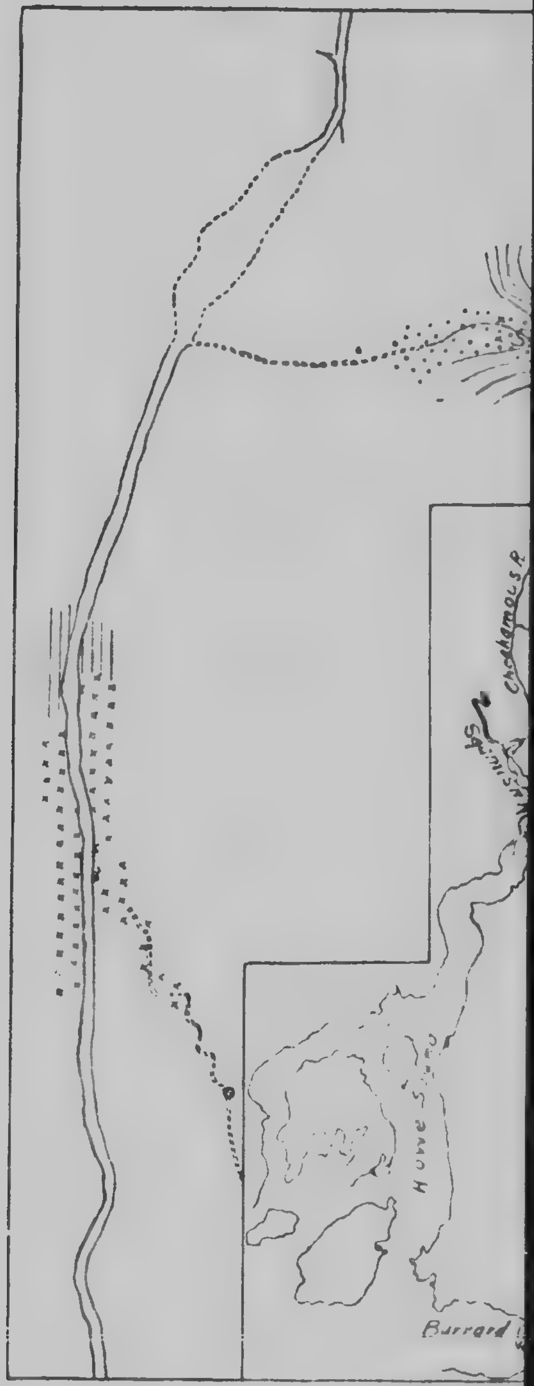
[1] Rosenbusch-Iddings, *Microscopic Petrography of Rock-forming Minerals*, p. 268.

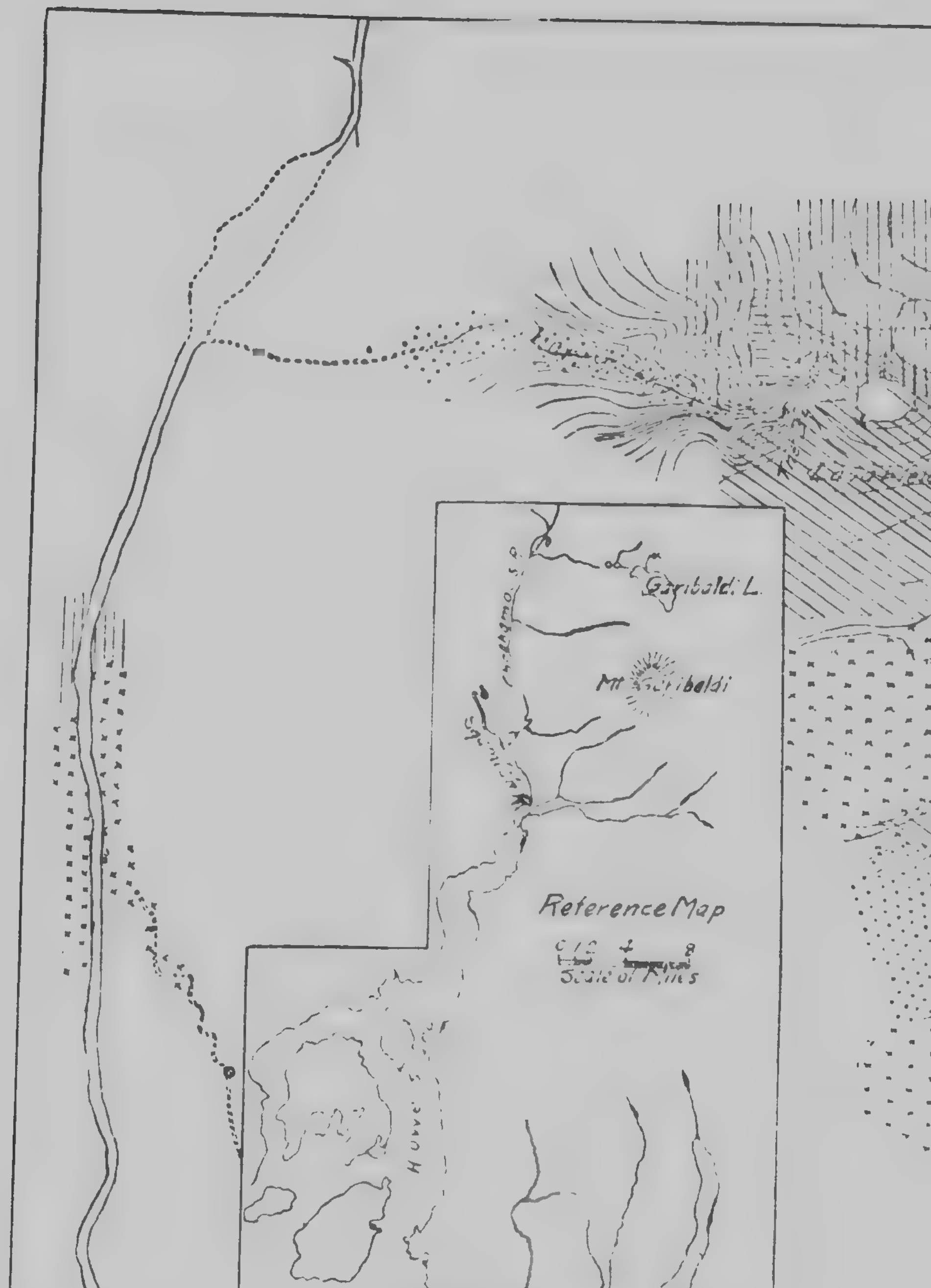
TABLE XI

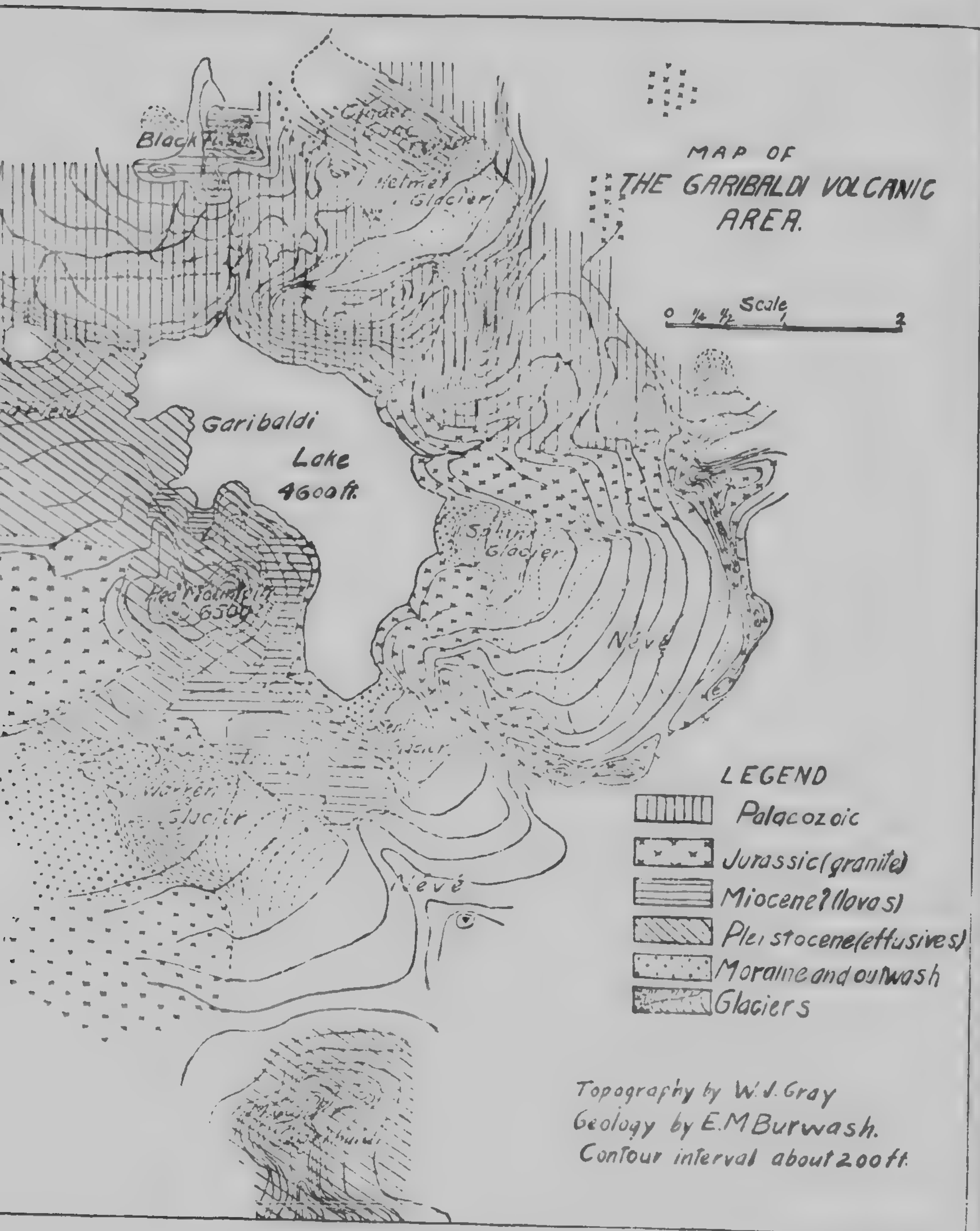
Locality	(1) West bluff of Black Tusk Ridge (lower member of series)	(2) Lava from the Black Tusk (upper part)	(3) East shoulder of Red Mountain (underlying volcanic cone)	(4) Columnar lava of The Table (upper part)	(5) [illegible] Lake	(6) [illegible]
Texture	Porphyritic	Porphyritic	Porphyritic	Porphyritic	Porphyritic	[illegible]
Color	Gray	Dark gray or black	Gray	Dark brownish black	Gray [illegible]	Dark gray
Jointing	Columnar or close parallel	Columnar	Distinctly, not perfectly columnar	Columnar	Columnar [illegible]	
Groundmass	Brownish glass with feldspar microliths and small augites	Brown glass with a felt of labradorite microlites and magnetite grains. In general appearance much like No. 4	Dark glass filled with minute feldspar laths and magnetite grains	Brownish glass [illegible] feldspar [illegible] general appearance much like No. [illegible] The glass [illegible] is in much greater proportions than in [illegible] lavas and gives [illegible] pitchy luster to the rock	Gray [illegible] glass [illegible]	[illegible]
Phenocrysts	Hypersthene laths. Augite magnetite resorption (pseudomorphs not seen in this section). Labradorite with central or banded inclusions, albite, and Carlsbad twins	No ferromagnesian phenocrysts, except a few laths probably hypersthene. Labradorite, rare individuals	Hypersthene laths and augites filled with inclusions of titaniferous magnetite after hornblende. Plagioclase varying from andesine interior to labradorite in outer zones. Also inclusions zonally arranged	A few hypersthene laths. Augite [illegible] filled with [illegible] Labradorite laths [illegible] and zonally arranged inclusions. Apatite needles occur also	[illegible]	[illegible]
Name	Hypersthene basalt	Labradorite porphyrite	Hypersthene basalt	Hypersthene basalt	Basalt [illegible]	Basalt [illegible]

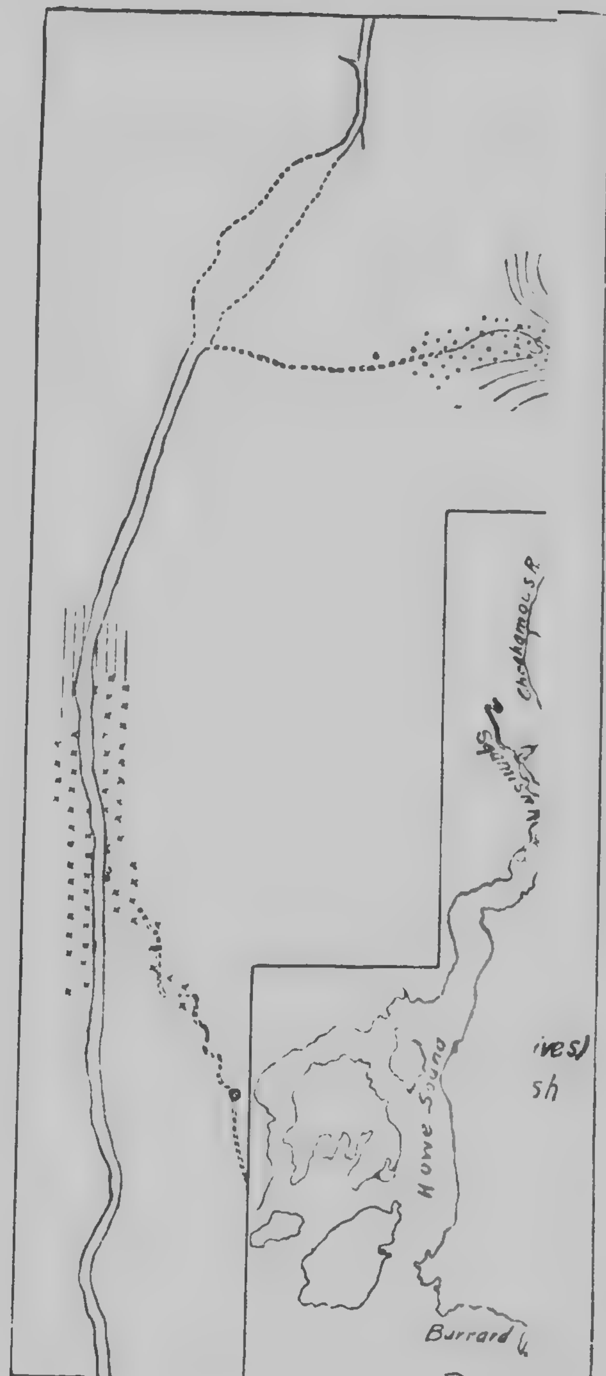


View of Red Mountain from Black Tusk Mountain. Lake Garibaldi [illegible] dam which consists of the [illegible] lava flows sloping gently to the right from Red Mountain. The notch in the [illegible] flowed.


Cheakamous R
Burrard


Garibaldi L.
Mt Garibaldi
Reference Map
Vancouver


MAP OF
THE GARIBALDI VOLCANIC
AREA.
Scale
0 1/4 1/2 1 2
Black Tusk
Helmet
Glacier
Garibaldi
Lake
4600 ft.
Glacier
Névé
Névé
LEGEND
Palaeozoic
Jurassic (granite)
Miocene? (lavas)
Pleistocene (effusives)
Moraine and outwash
Glaciers
Topography by W. J. Gray
Geology by E. M Burwash.
Contour interval about 200 ft.


Cheakamus R
Squamish
Howe Sound
Burrard

CHAPTER X

THE GARIBALDI VOLCANIC FORMATION[1]

A description of the Garibaldi volcanics, though somewhat foreign to the area which is more especially under discussion, is necessary to a complete conception of the geological history of the region. In brief, the formation consists, so far as at present known, of three volcanic cones, namely, Mount Garibaldi, Red Mountain, and a small cinder-cone northeast of Red Mountain, together with lava-flows which have manifestly originated from the same vents. The whole formation rests unconformably on a surface which includes Paleozoic roof remnants, granitic rocks of the denuded batholith, the older lavas (the Black Tusk basalts), and in some instances on Pleistocene glacial deposits. The cones themselves stand on a surface which is considered to be a valley floor of the Entiat stage of erosion, while the lavas have flowed in some cases into valleys of the Twisp and Chelan stages. The fact that no cones have been found in these lower valleys by LeRoy, Bancroft, or others who have made extensive studies of the coast and fiords at sea-level seems to indicate clearly enough that the commencement of the vulcanism took place before, or contemporaneously with, the uplift to which the Twisp canyon-cutting was due, and that the drainage lines were so deflected by the growing volcanoes as to locate the canyons elsewhere. There was a distinct erosion interval between the Black Tusk and Garibaldi lavas. The extrusion of the latter, therefore, probably began late in the Entiat stage of erosion.

On the other hand, the presence of lavas in the deeper valleys, or in some cases upon their sides, shows that the eruptive action continued during the excavation of the valleys. The lava area at Watt's Point on Howe Sound is of this type, since its base is near or in some cases below sea-level, and its position as a whole indicates a great addition to the depth of the valley since its deposition. It is in all probability an erosion remnant of a flow which made its way down the partly excavated Squamish Valley from Mount Garibaldi, a distance of twelve or fourteen miles. Remains of this or other flows may be seen resting on the east slope of the Cheakamous Valley along the Lillooet road. A flow from Red Mountain

[1] Cf. E. M. Burwash, *Journal Geology*, April-May, 1914, and *Papers Read before the British Columbia Academy of Science 1910–1913* (Vancouver, 1914), p. 67.

has completely dammed the valley of Stony Creek, a tributary of the Cheakamous, producing a lake three miles in length. This flow has every appearance of being recent in age, as it overrides morainic material and striated rock surfaces, and is itself entirely unglaciated, as is also the western cone of Red Mountain, from which it was extruded. Mount Garibaldi, on the other hand, has undergone a very considerable amount of degradation since its building, and its sides are deeply eroded by ravines and cirques, in which the quaquaversal dip of its stratified fragmental materials and lavas may be well seen.

The locus of the vulcanism lies well up to the axis of the Coast Range, since no traces of it have been found along the margin of the range between the mouths of the fiords. Mount Garibaldi is about forty miles from the southern edge of the upwarp, and the other cones from five to seven miles farther.

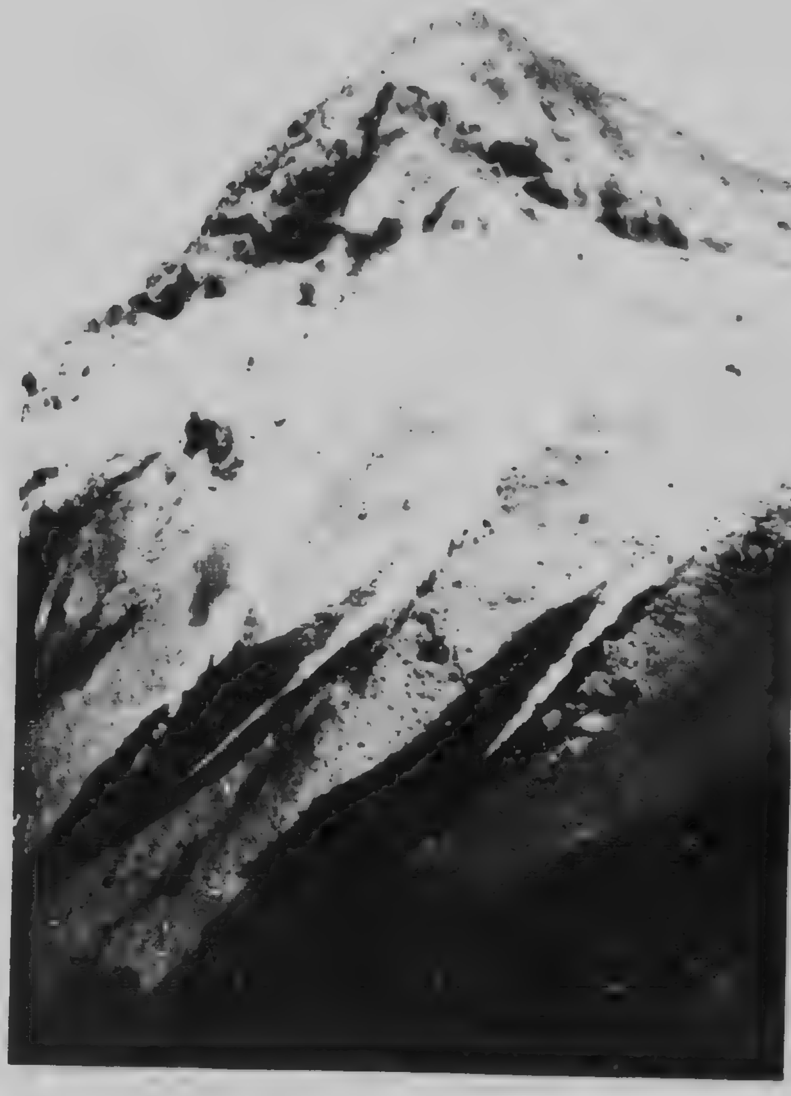
The time of extrusion of the later of these lavas would appear to agree in a general way with that of the red basalts at Miles Canyon and Whitehorse Rapid in the Yukon territory. The very recent flow mentioned by McEvoy[1] as having occurred within two hundred years at the Kit-wan-chilt Canyon on the Nasse River is probably later than any of those so far discovered near Vancouver. The occurrence of hot springs at Harrison Lake is no doubt genetically related to this recent vulcanism. It indicates that some traces of igneous action still remain in the region.

PETROGRAPHY

The small cinder-cone at the northeastern end of the volcanic area consists largely of scoriaceous materials with considerable amounts of ash intermixed. Microscopically the rock is composed of a vesicular groundmass which is nearly opaque from the presence of iron oxide, in which are distributed microliths of plagioclase and augite and phenocrysts of labradorite and olivine. It is therefore an olivine basalt.

The red lava from Red Mountain, which seems to represent the later stages of its activity, is a hypersthene basalt which has a groundmass partly optically dark and composed otherwise of a felt of labradorite microliths, magnetite grains, and small scales of hematite, to which the red color is due. Imbedded in this are resorption paramorphs of magnetite and augite, laths of hypersthene, and plagioclases which are mainly labradorite, but have zonal extinction, which indicates a composition which varies from oligoclase to bytownite. The more basic zones are toward the outside. The rock has undergone very slight alteration.

[1] *Geol. Surv. Canada, Summary Report*, 1893, p. 14.



The earlier lavas were gray in color and in appearance much like the gray lavas of the Black Tusk basalt. The groundmass contains some glass, magnetite grains, and microliths of plagioclase, but no hematite. The phenocrysts include large andesines of considerably rounded outline, with zonal extinction, brown basaltic hornblende, somewhat eroded and replaced pseudomorphously by augite and magnetite, and magnetite in large grains and aggregates. The rock is therefore andesite.

A specimen from the lower lavas obtained in the valley of Stony Creek consists of phenocrysts of labradorite and augite in a groundmass of the same minerals with grains of magnetite. This agrees closely with the basalt of Watt's Point (see Table XI, p. 76).

It will be seen that the character of the extrusion varies considerably, but is on the whole basaltic. A few small dikes were observed whose lithological composition and unweathered condition suggest that they may be traceable to the vulcanism of this period. In the bed of the brook that flows eastward from Mount Strahan one such dike of dull black color traverses the Triassic (?) porphyrite. In a groundmass of plagioclase, magnetite, and augite it contains phenocrysts of augite, labradorite, and olivine, the latter completely altered to serpentine and calcite. The augite is quite fresh. Serpentine has penetrated the feldspars along cleavage planes, but no kaolinization was observed.

Another dike at the Swayne copper claims in the valley of Lynn Creek has a groundmass of brownish glass containing plagioclase and augite microliths and magnetite grains. The phenocrysts are fresh augite and a few laths of plagioclase, probably labradorite. A little hematite is also present.

CHAPTER XI

QUATERNARY DEPOSITS AND PHYSIOGRAPHIC HISTORY

PLEISTOCENE DEPOSITS

The tills and other sediments which represent the Pleistocene period are distributed unconformably over all the older formations, both of the lowland and of the mountain sections. In the lowland they form a nearly continuous drift-cover, interrupted only by a few protruding outcrops of Eocene sediments and post-Eocene eruptives. In the mountain section they approach continuity only in the lower (Chelan) valleys, whose sides they cover, with some interruptions, up to 2,000 feet, as in the Capilano Valley. In other cases the continuous drift-cover is confined to a few hundred feet at most above the valley floor. On the more level Entiat uplands small areas of till, generally of no great thickness, also are to be found. A notable morainic ridge is that which projects from the south side of Grouse Mountain, at the mouth of the Capilano Valley. Its top has an elevation of about 1,100 feet. It is a terminal moraine of the Vashon ice. On the west side of the valley there is a projecting ridge which may represent the opposite end of the same moraine.

Drift-sections.—The best drift-sections of the region, so far as known, are those which were studied by the writer in the following locations:

1. The Capilano Valley.
2. The Lynn Creek Valley.
3. The Lower Seymour Valley.
4. The cliff on the north side of Point Grey.
5. Test borings in the city of Vancouver, to the south of False Creek and English Bay.
6. Road- and railway-cuttings, ravines, brickyard, and other excavations at New Westminster.
7. Ravines and railway-cuttings in the Surrey terrace to the south of New Westminster.
8. The section exposed on the east side of Boundary Bay.

The succession of deposits observed in the Vancouver area is in the main identical with those named by Willis in the Puget

Sound region and described at length by Bretz.[1] The series is as follows:

5. Outwash and delta sands and gravels
4. Vashon till.
   Unconformity (Puyallup interglacial period).
3. Admiralty clays and sands.
2. Admiralty till.
1. Nikomeki sand and silt.

1. *The Nikomeki sand and silt.*—This name has been given to the lowest member of the series which is exposed in the sea cliff at Mud Bay, just south of the Nikomeki River. It consists of stratified sediment of a somewhat silty texture. This underlies the lower of the two till sheets and is therefore pre-Admiralty in age. The beds dip toward the south and may very possibly have been foreset beds of a pre-Admiralty delta of the Fraser, since they occur immediately to the south of the most southerly of the channels occupied by its interglacial distributaries, whose antecedent valleys cut their way down to the present sea-level or below it during the later part of the Puyallup uplift.

Everywhere on the lowland the glacial deposits are unconformable on the Puget series and on the basalts which intrude them. Since the Miocene and Pliocene are here unrepresented by sediments, it appears that they together formed a period of erosion, when the land stood nearly up to or above its present level. Moreover, as the lowest Pleistocene beds present are water-laid sediments, we must postulate an early Pleistocene (pre-Admiralty) submergence. No fossils have been found in the Nikomeki beds, but their position renders it practically certain that they were marine. If, as has been suspected,[2] there should be found a third till sheet underlying the Admiralty, we have evidence of both glaciation and submergence in pre-Admiralty Pleistocene time. Since the Nikomeki is here immediately overlaid by the Admiralty till, it is probably younger than the oldest till, if there is a till older than the Admiralty. In the absence of an exposure of the oldest till in the Vancouver field this point remains uncertain.

2. *The Admiralty till.*—This name was given by Willis to the older of the two tills which are exposed on Admiralty Inlet, Puget Sound, and since the deposits in the Puget Sound region appear to correlate accurately with those in the Vancouver field, the name Admiralty will be used in the present paper to designate the lower of the two well-defined till sheets which are present.

[1] H. J. Bretz, *Washington Geol. Surv., Bulletin* 8. [2] *Ibid.*

Where both till sheets are exposed, the Admiralty is usually the thicker of the two. It is unweathered in many places, owing to the protection of the overlying sediments, which were deposited upon it immediately after the retreat of the ice. Its color is in general bluish gray. Most of the included bowlders were derived from the Coast Batholith, a smaller number from the Paleozoic formations and the post-Eocene and Pleistocene basalts, and occasional fragments of Eocene sandstone in the southern part of the area. The bowlders of this lower till are, in some places at least, more rounded than those of the upper. They exhibit well-glaciated surfaces.

The thickness of 480 feet, mainly till, which was penetrated by the boring at the Burns Packing House, Vancouver, is probably in the main to be assigned to the Admiralty till, although the thickness is much smaller on the higher parts of the northern ridge of Burrard Peninsula. At Fairview Heights, to the south of False Creek, the post-Eocene eruptive basalts project completely through the drift.

The greatest thickness of till observed in any exposed section which could be assigned to the Admiralty drift-sheet is about 100 feet. This is exposed near the Fraser River bridge at New Westminster. In the Brunette Creek valley, where stratified clay is seen resting on the Puget sandstone and overlaid by Vashon till, the Admiralty till is entirely absent. The thick deposits of this till from New Westminster westward give the impression of a recessional moraine belonging to the last stages of the Admiralty piedmont glacier fed by the glaciers of the Capilano, Lynn, and Seymour valleys. Their topographic expression has since been largely obscured by the deposition of clays, sands, and till, and later terrace-cutting due to wave-action of the Fraser estuary in recent time.

The Admiralty till is not seen in the Surrey terrace, which it probably underlies below sea-level, but reappears again in the Boundary Bay section to the south. It has there a thickness estimated at 40 feet. Its reappearance undoubtedly indicates an upward folding of the Puget formation beneath, which reappears again at sea-level to the south of Bellingham Bay. The Fraser Valley has thus a structural origin represented by a wide gentle syncline of the Puget formation.

In the mountain valleys the Admiralty till is the lowest drift deposit seen, and is undoubtedly the first till deposited after the rounding of the canyons by glaciation. This rounding of the valleys, elsewhere described as the Chelan stage of erosion, is therefore to be attributed to the ice of the Admiralty epoch. The valleys, in addition to being rounded,

were deepened in their narrow parts to the extent of several hundred feet. This is shown, for example, by the fact that the rock barrier which crosses the mouth of the Capilano is at least 200 feet higher than the valley floor to the north of it, which has some thickness of drift above the rock. Two hundred feet then would seem to be a minimum for the ice-cutting in this valley. Again the Stehekin rock-cutting at the mouth of the Lynn Creek Valley is at least 150 feet deep, and that at the Seymour Canyon is estimated at 200 feet. These figures represent minimum depths of ice-cutting above. In Howe Sound a depth in the upper reaches of 940 feet decreases to about 300 or less off Whyte Cliff Point, and in the North Arm of Burrard Inlet the maximum depth about two miles north of Lake Buntzen outlet is 672 feet, while near the mouth, opposite Turtle Head, it is 100 feet or less. In the submerged valleys it is, of course, impossible to estimate the thickness of drift which overlies the rock bottoms, and the actual depth of the ice-excavated rock basins cannot be fixed accurately, but the foregoing are minimum figures. It is evident that the bottoms of the Twisp valleys before glaciation must have been above the tops of the present glaciated rock barriers, and that the depth of the excavation accomplished by the glaciers must, therefore, be greater than the figures cited above indicate, since the tops of the rock barriers themselves suffered some glacial erosion. It is also extremely probable that the altitude of the land, or at least of the Capilano-Lynn-Seymour region, was somewhat lower than now at the close of the Twisp epoch, since its present elevation would necessitate extremely steep grades in the lower part of the Twisp canyons, amounting to 140 or more feet in the mile in the case of the Capilano. If 50 feet per mile, which is high, were allowed for the gradient in the lower Twisp Capilano Canyon, the land at the close of the Twisp must have stood at least 275-300 feet lower than now.

The data for a reconstruction of the Admiralty ice conditions are not as complete as those of the later Vashon glaciation, since the rounding of summits, especially where striations are present, and the deposition of erratics were in all probability done by the last glaciation. There are some peaks, however, of which Crown Mountain, Mount Brunswick, the Saw Tooth Mountains, and Black Tusk Mountain are examples, whose summits show no signs, so far as form is concerned, of having been glaciated at any period. Crown Mountain is 5,500 feet high and is well over 4,000 feet above the valleys on either side—in one case nearly or quite 5,000. This would allow for a thickness of at least 4,500 feet of ice for both glaciations. On the other hand, there could not have been a much

greater thickness near Crown Mountain without overriding its summit—but in Howe Sound, to the west, the bottom is 800 feet below sea-level, and if the ice there rose as high as at Crown Mountain there was a thickness of nearly 6,000 feet. In Howe Sound, about six miles farther north, there is evidence of somewhat greater thickness. There Mount Brunswick pinnacle presents a rounded dome of 5,600 feet altitude, while the depth of Howe Sound, immediately to the west, is about 800 feet. A total ice thickness of 6,200 feet might therefore be inferred here, provided no allowance is made for possible faulting. The Black Tusk Mountain, forty miles north of Burrard Inlet, has glaciated surfaces up to 6,500 feet or more, while the adjacent valley of the Cheakamous River is about 1,200 feet above the sea. An ice thickness of 5,500 feet would therefore not be an excessive estimate for the central part of the range. These figures, however, apply to Vashon rather than to Admiralty glaciation. They could not be much larger for the Admiralty, but might be less.

There are some facts which indicate that the Admiralty glaciation, if not more massive, was more prolonged than the Vashon, namely: (1) While it appears that the Admiralty ice excavated hundreds of feet of rock in the valleys, the later Vashon ice did not even remove the Admiralty drift from their bottoms. The drift is about 100 feet in thickness and of course unconsolidated. (2) The drift deposits of the Admiralty epoch contain much more material, in general at least two or three times as much as those of the Vashon.

This, however, must be in part at least attributed to the fact that the Admiralty was preceded by the Twisp uplift and subsequent erosion, which resulted in the formation of canyons whose rugged sides and salient spurs offered much resistance to the passage of the ice, and were consequently much eroded, while the presence of much erosional débris in the form of talus blocks, bowlders, gravel, etc., furnished the bottom of the ice with cutting materials. The frequent appearance of rounded bowlders in the Admiralty till suggests that they were produced by the preglacial stream erosion. On the other hand, the Vashon ice moved over surfaces already shaped by ice passage and robbed of extensive talus deposits and gravels. These had not been replaced by the comparatively slight erosion of the Puyallup interval, which was not sufficient to remove the drift from the valleys.

Since the distance to which a glacier can reach from its source of supply depends, the underlying slopes being equal, upon the thickness of ice at the source, the fact that the Vashon ice probably extended

about as far south in the Puget Sound valley as did the Admiralty[1] is evidence that there was no great difference in thickness of ice between the two epochs. Since the Vashon overrode the greater part of the range as a continuous ice sheet, with a few projecting nunataks, it is probable that the Admiralty ice did so too.

If we place the upper surface of the ice at the present 5,000-foot level on Crown Mountain, it was at least 3,500 feet above sea-level at that point, and if Howe Sound and the Capilano Valley had the same relative depths as now, the bottom of the ice exerted an active erosive force at 2,000 feet below sea-level in Howe Sound.

At the close of the Admiralty glaciation, part, if not all, of the region was 1,300 or 1,400 feet lower than now, as evidenced by the stratified clays deposited conformably over the till in the Lynn and Capilano valleys. If so, this was a deeper submergence than that which existed at the close of the Vashon, and hence a thicker ice sheet would be necessary to extend as far south in the Puget Sound valley, and if the Vashon extended somewhat farther the depth of ice was probably not far from equal in the two glaciations.

Bowlders of the Pleistocene lavas of Mount Garibaldi are found in the Admiralty till of the Capilano Valley, but not in the Vashon till. This appears to indicate that the last stages of the Vashon glaciation were more confined to local valley glaciation than were the last stages of the Admiralty, since the presence of these bowlders involves their transportation by ice across several divides of at least 5,000 feet altitude. It may also have been influenced by the greater activity of the volcano during the first glaciation, which would load the ice surface with ejectments.

3. *The Admiralty sediments.*—Resting on the Admiralty till throughout the locality is a deposit of clay, stratified sand, and gravel which is probably of marine deposition. In the valley of Sisters' Creek, where a good section is exposed, the sediment is well-laminated blue clay about 50 feet thick and overlies the till conformably, each passing by a thin gradation into the other. The clay may be traced down the Capilano Valley to the rock barrier at the canyon. Here it rises over the barrier. and descends again on the southern side. No sand was associated with the clay in the Sisters' Creek section, but at lower altitudes it is generally present. The elevation reached by the clay here is about 1,200 feet. In the Lynn Creek Valley at an elevation of 700 feet about 20 feet of similar clay occurs, overlaid by roughly stratified sand and gravel which contains logs of wood in a good state of preservation. It is not certain

[1] J. H. Bretz, *Glaciation of the Puget Sound Region*, p. 17.

that these upper deposits should be considered as belonging to the Admiralty sediments. They are probably modern "wash." Another section of stratified clay occurs at an elevation of 1,300 feet in this valley.

On the lowland the sediments are commonly found underlying the upper till and exposed in the sides of wave-cut terraces or ravines which have been cut through the drift. In North Vancouver they are seen on Keith Road at an elevation of 175 to 200 feet. On the north side of the Fairview Heights a number of borings made by the Burrard Peninsula Joint Drainage Board have penetrated these sediments, which there consist of blue clays, with some lignite in streaks, sand, and gravel. The slightest thickness observed was 7 feet. The deepest holes did not penetrate to the bottom of the deposit, and the maximum thickness to which these deposits were penetrated was about 12 feet.

At New Westminster these stratified deposits are exposed in a ravine at the Glen Road bridge (210 feet altitude), near the Brunette Creek on Columbia Street (100 feet), in the Great Northern Railway cuttings, at the interurban railway siding east of Edmunds between Eighth and Sixth streets, and at the Schaake Machine Works. They vary in level here from near sea-level to about 380 feet. The thickness of the deposit at Glen Road is about 25 feet. In the New Westminster brickyard excavation the section exposed was:

3. Fifteen feet stratified brick clay.
2. Two or three feet clear sand.
1. A fine stratified silt, whose lower limit was not exposed. Said to contain too little sand for use in brickmaking.

A hundred yards farther south the clays gave way to stratified sand and gravel. At the Brunnette Creek bridge on Columbia Street 10 feet of stratified sand is found underlying about the same thickness of laminated clay.

In the Boundary Bay section the sediments are sand and clay, or silt, sand, and gravel, which have a total thickness of about 80 feet.

These sediments indicate with certainty that at the close of the Admiralty glaciation the land was much below its present level, and also below the sea-level of the end of the Twisp stage, which immediately preceded the Admiralty glacial epoch. The nature of the sediments (interstratified sand and clay) on the lowland suggests quiet, but not very deep, water. Where they underlie the clay the sands may indicate deposition of coarser sediments nearer the ice front, during its retreat, followed by finer sediments deposited at a distance from the ice front. The occurrence of occasional bowlders in the stratified clay shows that

their deposition took place during the retreat of the ice, while floating ice was still a factor in deposition.

If the relative levels of the lowland and highland sections were the same as now, a submergence of about 1,300 feet was necessary, but it is possible that the uplift since has been of a differential nature and that the mountains have risen more than the lowland, since the sediments rise upstream from 200 feet at Burrard Inlet to 1,300 feet in Lynn Valley, about eight miles northward. It is noticeable that sands rather than clays are found at the higher exposures on the lowland.

After the recession of the ice the prevailing condition must have been that of a broad estuary which covered the lowland, while fiords occupied the mountain valleys. The deposition of the sediments must have occupied some time before upward movement brought the sediments up to sea-level. It may be that the subsidence continued after the retreat of the ice, since sand underlies the clay in part. The alternative suggestion above made agrees best with the gradation from till to clay directly, which occurs elsewhere.

In the stratified sand at Central Park, which almost certainly belongs to the Admiralty sediments, a number of shells have been found, some 20 feet below the surface of the ground (and between 350 and 400 feet above sea-level), and are now in the Art, Historical, and Scientific Society's Museum in Vancouver. They are probably *Mya truncata*,[1] but possibly *Mya arenaria*. Both of these species inhabit the coast at the present time, and both have been reported as fossils in glacial deposits.

Economic.—The sands and clays of the Admiralty sediments in the vicinity of Vancouver are being utilized extensively in brickmaking and concrete construction. Anvil Island, and other points on Howe Sound, at New Westminster and at Port Haney, are among the places where brick manufacture is carried on. Tables XII and XIII[2] indicate the composition of the brick clays.

TABLE XII

Locality	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alkalies	H_2O
Port Haney	58.5	21.1	8.6	6.50	0.5	0	4.80
Anvil Island	58.6	26.7	7.5	4.00	Tr.	0.2	3.00
Howe Sound	60.6	24.00	7.6	1.00	0.3	0	7.00
Average for district	60	20	9	4	0.1	0	5.00
Average Wisconsin glacial clays	68.82	13.62	4.84	1.48	1.53	4.50	4.88

[1] See paper by G. W. Taylor, *Roy. Soc. Can. Trans.*, N.S., Vol. I (1895), sec. 4, p. 52

[2] *Report of the Minister of Mines, British Columbia*, 1908.

These correspond approximately with the mineralogical compositions shown in Table XIII.

TABLE XIII

Locality	Kaolin	Free Silica	Impurities	Total
Port Haney	53.38	26.38	15.6	102.66
Anvil Island	61.97	27.20	10.3	99.9*
Howe Sound	60.72	32.95	8.9	102.57
Average	50.60	30.60	13.1	100.17
Wisconsin	34.45	47.98	12.35	99.60

* The Anvil Island clay probably contains some unkaolinized feldspar, and the Port Haney and Howe Sound clays somewhat less

As compared with the Wisconsin drift-clay, which is an average of several analyses given by Bleininger[1] as typical clays, the Vancouver clays are much higher in kaolin, notably higher in iron and lime, and lower in silica, magnesia, and alkalies. The reason for the difference is, of course, to be found in the composition of the rocks from which the clays were derived. The Wisconsin drift-clays were formed largely from the débris of granitic Archaean rocks or their derivatives; those of the coast, from dioritic rocks. Table XIV gives a comparison of granite and diorite which will indicate the difference in composition.

TABLE XIV

Rock	SiO_2	Al_2O_3	Iron, as Fe_2O_3	CaO	MgO	Alkalies		H_2O
						K_2O	Na_2O	
Average sample of pre-Cambrian granite	68.87	16.23	2.91	1.99	0.86	3.66	4.09	0.53
Coast diorite	56.97	19.12	6.44	8.99	2.21	0.26	6.16	0.50

In the leaching process sodium, magnesia, and lime are lost to a much greater extent than potash or silica, while the relative amounts of alumina and iron are increased, owing to their greater insolubility. This holds true in clays produced by weathering of the rock.

In the glacial drift-clays there appears to be an actual increase in silica also as compared with the original rock, due partly, no doubt, to the fact that the sediment is glacially produced rock flour, in which the free silica has been, to a large extent, ground fine enough to be transported

[1] *Geol. Surv. Illinois, Bulletin 9*, p. 13.

with the kaolin in suspension, and solution has had a very short time to act as compared with the time occupied in the production of residual clays by weathering.

4. *Puyallup erosion-interval.*—Uplift succeeded the period of deposition, just referred to, and the sediments were subjected for some time to erosion. A halt seems to have occurred when the land was slightly more than 200 feet lower than now, during which the Fraser developed a delta or bars of sand and silt whose remaining portions are the Surrey terrace, the higher part of Point Roberts, and the western end of Point Grey. The last-mentioned affords probably the best section. It consists of sand and gravel at the eastern end, near Kitsilano, passing into somewhat argillaceous sands farther west. The sands exhibit cross-bedding and in some parts "flow-and-plunge" structure. The thickness above sea-level at the end of the point is 230 feet. The deposit was probably a projecting spit at the end of the Burrard Peninsula island. The deposits of the Surrey terrace are sand and silt, with peaty material interbedded.

The Surrey deposits may have been a sand bar rather than a delta, since there must have been deeper water in the upper part of the estuary while the deposition was in progress at its mouth, or else the upper part of the delta has been washed away since, which seems an improbable assumption.

LeRoy[1] suggests that the retiring ice front was at this time at the eastern margin of the Surrey terrace area, and that the deposit is an outwash delta formed at its foot. This would perhaps account for the lower level of the valley floor to the east, but on this hypothesis one would expect coarse deposits of gravel rather than silts with peaty material such as are exposed in the recent ravines near South Westminster. The most probable explanation seems to be that the current in the upper estuary was sufficient to move these materials down to its mouth, where they were deposited in the form of silt islands or a bar somewhat like that which exists at present off the mouth of the Columbia River. During the maximum glaciation, the Fraser was probably non-existent, but during retreat of the ice sheet it must have been swollen to unusual size, since its drainage basin includes most of the southern half of the Cordilleran ice sheet. Its current, therefore, combined with tidal action, might have been strong enough to transport the finer materials to the positions where they now lie, where the stream issued finally into the quiet waters of the Gulf of Georgia.

[1] *Op. cit.*, p. 8.

It is probable that the Brunette–False Creek channel and the Burrard Inlet channel were kept open by the current, since no remains of bars have been found at their mouths. The materials which were carried out through them were deposited at the seaward end of the western Burrard Peninsula island and now form the sand deposit of Point Grey.

The topography south of the international boundary would indicate that the Fraser estuary must have had other outlets southward, from Sumas through the Nooksack Valley, and at Blaine and Bellingham Bay. These deposits are all overlaid by Vashon till.

At the corner of Seneca Street and Sixth Avenue in Seattle there is a similar deposit which is described by Bretz.[1] It consists of foreset beds of silt with streaks of lignite, overlies the Admiralty sediments unconformably, and is overlaid by the Vashon till. The contact between the foreset beds and the till is at 200 feet elevation. This corresponds accurately with the deposits above described in the Surrey delta terrace in all details, except that no contact between the Admiralty sediments and the silts was observed at the latter place. Bretz suggests tentatively that the Seattle deposit may have been formed in an ice-dammed lake during the advance of the Vashon glacier, but the explanation offered above seems to fit the conditions better in the Vancouver area.

After the building of the bar across the mouth of the estuary a further uplift occurred which brought the land nearly to its present level, and a number of antecedent distributaries were cut in the sand deposit. These include the Nikomekei-Serpentine channel, the channel at present occupied at New Westminster, and probably also the Burrard Inlet and Brunette–False Creek channels. The last two had undoubtedly been cut in the Puget sandstone during the Twisp epoch and were occupied by the river during the bar formation. The erosion later involved only clearance of débris from the channels.

On the higher parts of the lowland which were above water during the bar formation erosion progressed far enough to produce an erosional topography, which had in fact mature valleys at the 200-foot level or a little higher. In many places the Admiralty sediments were entirely removed, and they now occur in patches which occupy hollows in the surface of the Admiralty till. Both are now overlaid unconformably by the later Vashon till. The length of the Puyallup erosion interval is indicated by the fact that the bowlders of diorite in the Admiralty drift are weathered completely through for several feet below the surface, so that they cut easily with the spade in making excavations. Very little

[1] J. H. Bretz, *op. cit.*, p. 114

Fig. [illegible] Glacial section in a cutting on Kerr Road [illegible] M[illegible] [illegible]
Admiralty till [illegible] the [illegible]

iron-staining was observed, however. In the overlying Vashon till, on the other hand, the bowlders are hard and weathered only for half or three-quarters of an inch from the surface, while the thin till sheet is generally stained throughout. The greater oxidation of the Vashon till may be due to its more sandy composition and greater porosity.

This stage of uplift and erosion has been named the Puyallup interglacial epoch. Bretz states that in the Puget Sound region the land early in the Puyallup epoch stood probably 1,000 feet higher than at present. In the Vancouver region there is nothing that would necessitate a level much higher than the present, unless ice erosion is neglected as an agent competent to deepen the fiords. At the maximum of the Vashon glaciation he says the sea stood about 50 feet higher than at present, which corresponds very well with the evidence in the Vancouver field.[1] The length of the Puyallup epoch, as indicated by erosion and weathering, was longer than the recent.

5. *The Vashon till.*—The last glaciation of the Pacific Coast is represented by a till sheet which is in general much thinner than that deposited by the Admiralty glaciation and merely mantles the topography which had developed during the Puyallup interglacial epoch of erosion. The Vashon till varies in the exposures seen from 3 or 4 to about 50 feet in thickness, and over most of the surface the lower figures are much the more common. In the mountain valleys it overlies the Admiralty clays to a depth of about 50 feet. Both till sheets and the intervening sediments are found on top of the rock barriers at the mouths of the canyons and dip with the rock surface on either side. The Puyallup sands of Point Grey and the Surrey area are overlaid by a thin till sheet which contains bowlders of considerable size. The greatest thickness of Vashon till seen in any exposure was that at Sisters' Creek in the Capilano Valley.

The variability of the effect of the overriding ice on the underlying sediments is a very noticeable feature. At the top of the Burrard Peninsula ridge in the northern outskirts of New Westminster the Admiralty sands have been thrown into a series of folds and planed off, while on the southern slope near Brunette Creek on Columbia Street minute details of pre-Vashon stream erosion are to be seen (see fig. 20). The difference in the cases mentioned is probably due to the fact that the exposures are respectively on the top and the lee side of the ridge.

The Vashon till is in places weathered completely through and is of a dark-brown color. The bowlders included in it are, however,

[1] J. H. Bretz, *Washington Geol. Surv., Bulletin 8*, p. 21.

comparatively fresh, while those in the upper part of the Admiralty drift are often decomposed.

The Vashon ice sheet is said by Bretz[1] to have been at least as great in extent as the Admiralty, although its morainic records are

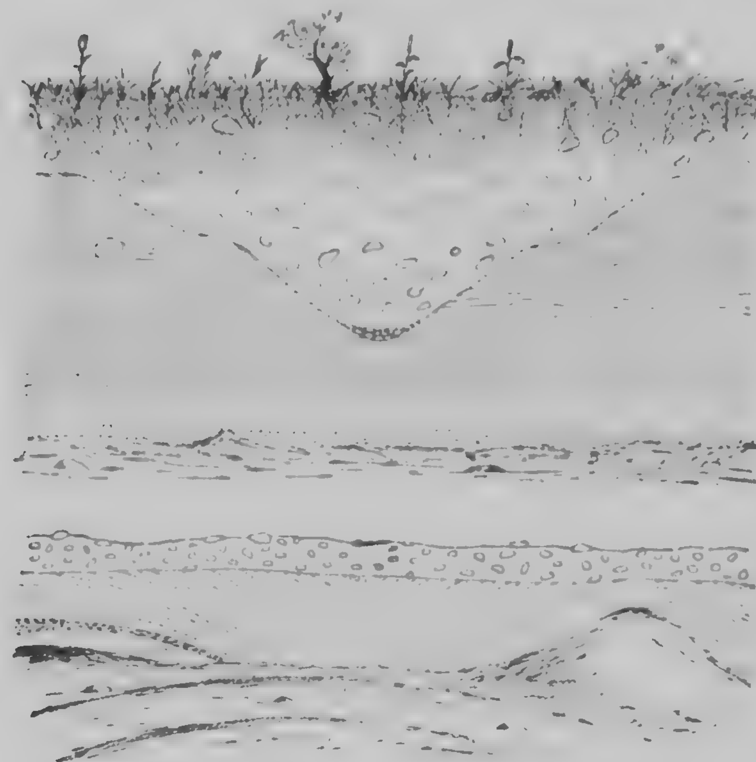
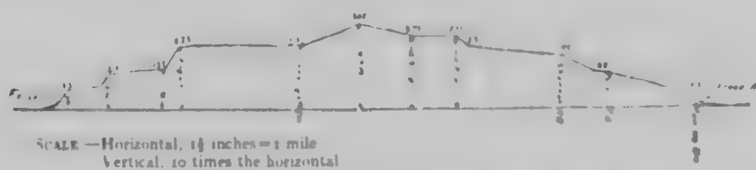


FIG. 20. a, Vashon till; b, c, Admiralty sediments

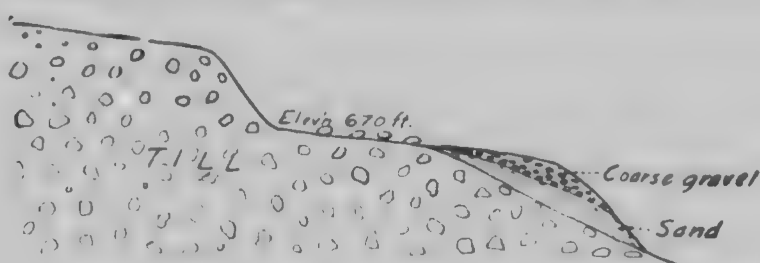
comparatively meager. The latter fact may have been due to a retreat more rapid than that of the Admiralty ice, but for reasons already given (p. 84) we must also infer that the Vashon had less erosive effect. Striations and erratics on the summit of Mount Strahan (5,000 feet) show that the surface of the ice was at least above that elevation where it descended from the Coast Range. The bottom of Howe Sound, adjacent

[1] *Op. cit.*, p. 17.

to Mount Strahan, is 800 feet below sea-level. The ice thickness was therefore nearly 6,000 feet. Forty miles farther north on Black Tusk Mountain the upper limit of the ice was between 6,500 and 7,000 feet in altitude, while the adjacent Cheakamous Valley is not over 1,200 feet. The thickness there was therefore from 5,300 to 5,800 feet. In its retreat outwash deposits overlying the moraines were deposited in the Lynn and Seymour valleys, and along the south side of Burrard Inlet or the north slope of North Mountain certain coarse deposits of bowlders



Section across the south ridge of Burrard Peninsula on the line of Granville Street



Section of terrace at corner of Osborne Road and St. George's Avenue, North Vancouver, B.C.

FIG. 21

and sand are so interpreted. The very large valley train which was deposited in the Fraser Canyon above Hope is worthy of mention also.

As already noted, the recessional stages of the ice were recorded by the cutting of cirques at successively higher elevations, and especially upon the northern slopes of the mountains. These are in some cases so extensive that they include in their vertical development nearly the whole of the topographic stages below the Methow and above the Stehekin, but ordinarily are confined to one or two.

Recent movement and deposition.—At the close of the Vashon glaciation the sea stood at a level of at least 760 and perhaps 800 feet higher than now. As indicated by the absence of stratified drift, a comparatively rapid rise took place, whose resting stages are marked by terraces.

TABLE XV

Correlation Table of Postglacial Wave-Cut and Delta Terraces

Table XV indicates the extent to which it has been possible to correlate these over a distance of 50 miles from Howe Sound to Mission Junction in the Fraser Valley. The best recorded stages are those at 600, 440, 400, 300 275, 225, 175, 110, 80, and 60 feet. The upper terraces are cut in Vashon till, with beach deposits upon their tops, in which, as yet, no marine shells have been found. Shells have, however, been found in the till itself. A striking coincidence exists between these levels and those assigned to glacial lakes in the Puget Sound region[1] which are as given in Table XVI.

TABLE XVI

	[illegible]	Vancouver
Lake Puyallup (Chop stage	550 feet	
Lake Puyallup (Clover Creek	400 "	4[illegible] feet
Lake Skokomish	350 "	
Early Lake Tacoma	3[illegible] "	3[illegible] feet
Lake Sammamish	[illegible] "	300 "
Lake Snohomish	[illegible] "	[illegible]42 "
Lake Tacoma	[illegible] "	[illegible]35 "
Lake Hood	2[illegible] "	[illegible] "
Lake Misqually	1[illegible] "	175 "
Lake Russell	1[illegible] "	150 "
Lake Russell	120 "	115 "

The coincidence in the height of these levels with the terraces at Vancouver seems much too great to be accidental, and the writer has not been able to decide how the ice front necessary to explain the presence of a glacial lake could exist in Puget Sound contemporaneously with the cutting of marine terraces and deposition of deltas at Vancouver. If we suppose the Vancouver terraces to be formed in glacial lakes, the coincidences in levels remain unexplained, and very special ice conditions must be imagined. If, on the other hand, the sea stood at these levels after the entire retreat of the ice, the channels which are considered to have been the outlets of the glacial lakes would be invaded by the sea and, where the water was shallow, would be subject to the erosion of tidal currents, which might lower them considerably as the land emerged, if the divide was composed of drift.

The terraces up to 180 feet at the mouth of the Capilano and those up to 215 feet at the mouth of the Seymour Canyon are delta terraces formed by the streams in question and are composed of sand and gravel disposed in foreset and topset beds. Other streams, such as Cypress Creek

[1] J. H. Bretz, *Washington Geol. Surv., Bulletin 8.*

and those that flow down the steep slopes of the Strahan-Brunswick Range into Howe Sound, also have elevated delta terraces which are convenient to tidewater and are being utilized as a source of gravel and sand. The large sand deposit at Whyte Cliff, which forms a flat at about 225 feet, is probably of similar origin, but may be due to wave-action filling in a bay or channel between rocky islands and the main shore.

The flat-topped deposits of sand and gravel at Langley probably represent delta deposition by the Fraser when the sea stood at that level. They are about 50 feet above the present sea-level.

The present delta and flood-plains of the Fraser are composed of fine silt overlaid by peat deposits, which in some cases cover a considerable area. As they lie largely below sea-level and their upper surfaces are for the most part below spring tides, little is known as to their thickness. The sea cliffs at Point Grey, Point Roberts, and Boundary Bay, in each case about 200 feet in height, are furnishing materials for offshore deposition, but undoubtedly the greatest depositional activity of the present is that of the Fraser River. This is true, not only as to the delta front, but also as regards the formation of bottom-set beds which extend far out over the bottom of the Gulf of Georgia, whose waters are discolored by silt for many miles beyond the delta front. Gravelly deltas of higher gradient than that of the Fraser are also being deposited at the mouths of mountain streams. Of these, those of the Capilano, Lynn, and Seymour creeks are important, as they furnish extensive levels available for railway use adjacent to the harbor of North Vancouver. Deltas are also to be found at the heads of all the fiords.

PHYSIOGRAPHIC HISTORY OF THE PLEISTOCENE

The various erosion stages which are observable in the mountainous part of the region have already been described in general (chap. ii). It remains to consider their development in the area in question and the question of their correlation with the typical region in central Washington.

1. *The Methow peneplain.*—The name Methow peneplain has been applied by Willis and Smith to a peneplain which was developed in central Washington subsequent to the Miocene lavas and to the deposition of the (upper Miocene) Ellensburg formation.[1] The period when peneplanation was reached must therefore have been well on in the Pliocene or early Pleistocene. A subsequent uplift, effected in two

[1] G. O. Smith, *U.S. Geol. Surv., Folio 106*, Mount Stuart Quadrangle.

principal stages, with a long erosion interval following each, has produced the Cascade Range, in which the peneplain is now represented by accordant summits or terraces near the summits.

The Coast Range as a whole may be considered as a dissected flat-topped anticline. There has been little subsidiary folding, and the effect is that of an upthrust block bounded at the edges by monoclinal upwarps, but faulting has played a very considerable part in the resulting structure. The total uplift amounts to about 8,000 feet on the average in the center of the range. It occurred in a number of successive stages, beginning when the area now occupied by the range had been reduced to a peneplain near sea-level, above which rose a few monadnocks, erosion remnants of an older range. This peneplain is now represented by the warped surface to which the accordant summits of the range approximate, and by some parts of the profiles of the marginal spurs. In a few cases near the edge and also near the axis of the range there are considerable flat areas on the summits, but in most the summit is merely an approximation to the original surface. The accordance of summits, however, is very marked, and a plane projected through them exhibits the flat-topped anticlinal form to a striking degree.

In the Vancouver region there is no way in which the age of the summit level corresponding to the Methow of the Cascades can be so definitely fixed. The Eocene rocks of the Puget series have been involved in the upwarp on Malaspina Strait to the west of Jervis Inlet, and it would therefore appear that the planation was post-Eocene. Data are lacking, however, as to the truncation of the beds in that locality. In the vicinity of Vancouver the Puget beds are tilted and truncated, but their implication in the upwarped surface is not sufficiently clear to be demonstrative. It may be considered as proved, however, that the uplift of the range, or at least of the last stages of it, was post-Eocene. The Eocene strata are also intruded by trachytes, andesites, and basalts whose date can hardly be Miocene or younger. Lavas which are provisionally correlated with these occur in the higher parts of the range at Black Tusk Mountain and elsewhere. They appear to have been solidified in valleys whose bottoms lie considerably below the level of adjacent summits. At first view this would indicate that the valleys, and therefore the lavas, are younger than the peneplain. It is nevertheless possible that they are older, since the highest peaks composed of the lava are near the summit level, and others are faulted to a lower position. It would then be necessary to suppose that valleys which existed prior to planation were partly filled by lava, and the later

planation removed the intervening highlands down to the level of the lava. As the locality is only 40 miles from the sea, and the lava about 1,500 feet thick, there must have been subsidence enough to lower the bottom of the lava below sea-level before planation.

On the first hypothesis, that the lava is younger than the planation, the date of both remains uncertain, except that the upwarp of the peneplain was post-Eocene. The valleys might then have been early Miocene, or later, and the lavas late Miocene, or later. The stage of erosion which is correlated with the Entiat of Washington was subsequent to the lavas.

On the hypothesis that the lavas were older than the summit peneplain, the planation was probably of Pliocene or early Pleistocene date and contemporaneous with the Methow of Willis and Smith. The fact that it would be contemporaneous, together with the fact that the subsequent stages of erosion also correlate very well, offers some support to the second hypothesis.

The general character and warping of the summit plane have already been described (pp. 15-16) and need not be detailed here. The range as a whole may be thought of as a dissected plateau.

2. *The Entiat.*—The elevation of the summits above the lower flattish surfaces which are assigned to the Entiat stage varies within the region from 400 feet at Grouse Mountain, near the edge of the range, to about 3,000 feet in the neighborhood of Mount Garibaldi, 40 miles north. The latter figure is probably the amount of the Entiat uplift. Mature valleys were developed below the Methow after its first upwarp, which in some cases attained the depth noted above. In this stage of erosion the present drainage lines were therefore in general well defined, but many of the divides were low. The upper Capilano Valley may have been confined to its present western branch, while the waters of the eastern branch reached the sea by way of Lynn Creek. This is suggested by (1) the alignment of Lynn Creek with the upper part of the east branch of the Capilano, (2) a through valley or gap which crosses the divide between the two, and (3) the fact that the small stream which flows from the north side of the divide to the Capilano makes an acute angle with the Capilano on the downstream side. The valleys on both sides of the divide have since been developed by glaciation into large cirques, making conclusive evidence unobtainable.

At the end of the Entiat stage mature valleys had developed whose floors in the case of the Capilano and Seymour were about three miles wide, while the interstream uplands had been reduced to small dimen-

sions, and in many parts considerably lowered. A few still retained flat surfaces attributable to the original peneplain, but in most cases the divides were sharp. Black and White mountains near the coast, and Mount Mamquam inland, are flat-topped cases.

3. *The Twisp stage.*—The uplift following the Entiat stage extended the borders of the range laterally, so that the Entiat features are not found near the present coast or lowland. The vertical movement appears to have been nearly 4,000 feet near the coast and over 5,000 at the axis of the range, as shown by the present elevation of Entiat valley floors, 3,800 to 5,000 feet, and the depth of the canyons below them. The stream piracy already noted (p. 98) must have occurred, if at all, shortly after the uplift began, since the divide above Lynn Lake is now slightly more than 3,200 feet above sea-level and 450 feet above the lake in the cirque on the south side which forms the present headwaters of Lynn Creek.

The Capilano Valley above the waterworks intake is fully 3,000 feet deep, and the Lynn Valley near the forks is about 4,000. In the latter case the extreme steepness of the spurs and ridges renders the effect very striking.

4. *The Chelan stage.*—Near Vancouver, as elsewhere in the range, the rounding of the valley bottoms by glacial action is very marked. The Capilano Valley furnishes perhaps the most striking instance of rounded form, while Howe Sound displays the greatest amount of deepening. The question of valley deepening and the formation of rock basins has been considered under the Admiralty glaciation. The name "Chelan stage" is taken from the Lake Chelan region on the east side of the Cascade Mountains, where it represents the period of glaciation following the Twisp stage of uplift and canyon-cutting. In that region there is no record of two glaciations later than the Twisp. The term "Chelan," if applied to the coast region, must be made to cover the two periods of glaciation to which the names Admiralty and Vashon have been given in the Puget Sound region, since the glacial modification of the Twisp topography extended over both the Admiralty and the Vashon periods of glaciation. Willis makes the Chelan stage equivalent only to the last glacial epoch which affected the region, and hence the use that is made of the name here applies rather to its place as a stage in the physiographic development than to a time correlation. While it is not certain that two till sheets are to be found in all the deeper valleys, that is certainly the condition of affairs in the Capilano Valley wherever deep sections are to be seen, while the Lynn and other valleys

have exposures of laminated clays which are in all respects similar to the Admiralty clays. The Admiralty drift may have been removed by erosion in the Lake Chelan region.

In the Lake Chelan region the Entiat stage is stated to be contemporaneous with the first glaciation, if such an epoch of glaciation can be proved to have occurred; but the set of topographic features which in the Vancouver region correspond to the Entiat, both in position and in stage of maturity, must be placed before the last tw glaciations as well as an uplift preceding them. It is evident, therefore, that the physiographic correlation which has been made must be regarded as distinctly provisional.

The great uplift in the Cascades, amounting to 3,000 feet, which intervenes between the Entiat and the Chelan and involved the cutting of very large canyons could hardly be correlated with the slight uplift of the Puyallup epoch, followed by erosion during which a stream like the Fraser removed only 100 feet of drift at the greatest estimate, and other streams much less. Moreover, the pre-Admiralty uplift and erosion do compare very closely with the Twisp of the Cascades, both in amount of uplift and in the stage of development reached by the subsequent erosion before glaciation supervened.

5. *The Stehekin stage* consists of postglacial canyons. They are a well-known feature of the local scenery to which visitors frequently are directed. Their history began after the postglacial uplift had raised the rock barriers through which they are cut above sea-level. In the case of the Capilano this was 400 feet above the present tide-mark. East of the brink of the Capilano Canyon is a channel, about 30 feet in depth, which was cut in the top of the rock barrier and for some reason abandoned in favor of the present canyon, whose walls are not far from vertical, nearly 300 feet in height, and quite unglaciated.

The sinking of the land during each of the two glaciations (referred to on p. 86 and 93) suggests that the weight of the ice cap may have been effective in producing a readjustment of level. If the average thickness of ice over valleys was 5,000 feet and the average over the whole range 2,000, the weight of the ice would be equivalent to about 800 feet of rock of a specific gravity of 2.5, and 800 feet corresponds closely with the amount of submergence in the Vancouver region at the close of the Vashon glaciation. The Admiralty submergence appears to have been greater. It is to be noted, however, that a part at least of the postglacial uplift seems to have been common to the coast south of the Cordilleran ice sheet, as shown by the terraces on the coast of

Oregon at 225 and 500 feet above sea-level.[1] There also the local summit levels rise from 2,000 feet to 4,000 feet, and mature upper valleys which open upon terraces cut at 1,000 feet above the sea are incised by canyon-like inner valleys. These features recall strongly the Methow, Entiat, and Twisp stages elsewhere.

The correlation of the Stehekin stage in Washington with the cutting of the Capilano and other canyons is a matter which presents no difficulty. Both are obviously postglacial.

The Chelan stage.—The stage of the formation of U-shaped valleys, which, in this region, is shown to have occurred in the Admiralty glacial advance, is here made to include also the Puyallup and Vashon epochs. Its definition by Smith would include only the last glacial epoch. It has already been shown, if we extend the term Chelan to cover both the Admiralty and Vashon glaciations, that in it were included two subsidences with an intervening uplift. The reasons for correlating it as stated have already been outlined.

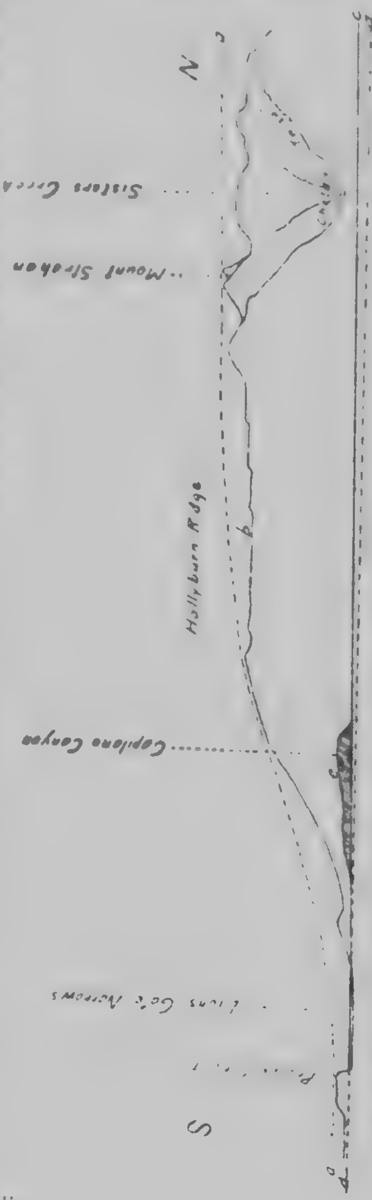


FIG. 24.—Profile of Hollyburn Ridge and valley of Capilano Creek. *a*, dotted line, near position of original "Methow" surface; *b*, "Entiat" features; *c*, profile of Capilano ("Twisp" and "Chelan"); *d*, sea level; *e*, rock barrier left by glacier near mouth of valley; *f*, Hachuring, postglacial ("Stehekin"), cutting of the Capilano Canyon. Scale 1¼ inches = 1 mile.

[1] *U.S. Geol. Surv., Port Orford Folio.*

The Twisp and Entiat stages, both as regards the amount of advancement which the ice reached in each case and in the total amount of uplift, correspond very well with the topographic types with which they have been correlated in this paper.

This general correspondence of the younger cycles of erosion in Washington with those in the Coast Range of British Columbia makes it appear probable that the summit levels in both cases represent the same planation, if they are to be referred to planation at all. In this matter Daly attacks the conclusions of Russell, Smith, and Willis in Washington, and his arguments might apply with equal force to the Coast Range of British Columbia.[1] His contention is in general that summit accordance is developed within a mountain range by causes which are spontaneous and independent of previous planation. In this he agrees with G. M. Dawson, who believes that differential erosion is sufficient to account for summit concordance. To this Daly adds isostatic adjustment, the more resistant qualities of the zone of metamorphism and the upper surfaces of batholiths as compared with the overlying unaltered or less compact terrains. It is stated that level-topped spurs, like those of the Entiat, might be developed below the summit levels by overriding ice, while the ice between remained stagnant, but it is not clear to the writer why in such case the spurs should be not only level but accordant over considerable distances measured at right angles to the movement of the ice. It is not denied here that they may have formed part of a surface glaciated by a pre-Twisp glaciation, and it is believed that they were overridden by both the Admiralty and Vashon glaciations after the uplift and erosion for which the name Twisp has been adopted. The present writer has made full use of the theory of uplifts following planation, since it correlates the physiography of the Coast and Cascade ranges very completely and seems on the whole to furnish the best explanation of the coincidences between the two regions, one of which was heavily glaciated, while the other was affected only by valley glaciation.

[1] R. A. Daly, *Geol. Surv. Canada, Memoir* 38, pp. [illegible]

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